PROCEEDINGS

# Illinois Crop Protection Technology Conference

JANUARY 8 & 9, 2002

*Serving Agriculture and the Environment*

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

UNIVERSITY OF ILLINOIS EXTENSION
COLLEGE OF AGRICULTURAL, CONSUMER AND ENVIRONMENTAL SCIENCES
IN COOPERATION WITH
THE OFFICE OF CONTINUING EDUCATION
DIVISION OF CONFERENCES & INSTITUTES

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# 2002 Illinois Crop Protection Technology Conference Planning Committee

## CO-CHAIRS:

**Suzanne Bissonnette**
Champaign Extension Center, University of Illinois Extension

**Bruce Paulsrud**
Department of Crop Sciences, University of Illinois

**Susan Ratcliffe**
Department of Crop Sciences, University of Illinois

**Christy Sprague**
Department of Crop Sciences, University of Illinois

**Elaine Wolff**
Conferences & Institutes, University of Illinois

## OTHER COMMITTEE MEMBERS:

**Steve Barrett**
Galesville Chemical Co.

**Chris Clemens**
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**Dennis Epplin**
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**Dave Feltes**
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**Aaron Hager**
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**Greg Hainline**
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**Gerald Kirbach**
Illinois Department of Agriculture

**Dean Malvick**
Department of Crop Sciences, University of Illinois

**Terry Niblack**
Department of Crop Sciences, University of Illinois

**Michael Rahe**
Illinois Department of Agriculture

**Jim Shearl**
Golden Harvest Seeds Inc.

**George Soltwedel**
Effingham Equity

**Joe Spencer**
Illinois Natural History Survey

**A.G. Taylor**
Illinois Environmental Protection Agency

**Paul Vassalotti**
BASF

**Dan Zinck**
Monsanto

# Program–January 8 & 9, 2002

## TUESDAY MORNING, JANUARY 8

| | |
|---|---|
| 9:00 a.m. | **Welcome and Opening Remarks** - Illini Rooms A, B, C<br>*Susan Ratcliffe* |

**Keynote Session: The Future of Agriculture**
(0.5 CCA credits in Crop Production)
*Todd Gleason, Moderator*

| | |
|---|---|
| 9:15 a.m. | Transgenic Technology: A Crop Protection Bargain?<br>*Leonard Gianessi* |
| 9:45 a.m. | Globalization and Exportation of Technology, *Steven Sonka* |
| 10:15 a.m.-<br>10:30 a.m. | **Break** |
| 10:30 a.m. | The First Farm Bill of the New Century - How Congress Can Address the Needs of the Entire Food Chain, *Mary Kirtley Waters* |
| 11:00 a.m. | Government Payments and the Farm Sector, *Neil Conklin* |
| 11:30 a.m. | Questions |
| 11:45 a.m.-<br>1:00 p.m. | **Lunch** |

## TUESDAY AFTERNOON, JANUARY 8

**Symposia A and B run concurrently with Seminars 1-5 from 1:00-2:30 p.m.**

**Symposium A: Plant Disease** - Illini Room A
(1.2 CCA credits in Pest Management)
*Dean Malvick and Suzanne Bissonnette, Moderators*

| | |
|---|---|
| 1:00 p.m. | Sudden Death Syndrome and Soybean Cyst Nematode in the Field, *Jason Bond* |
| 1:15 p.m. | Varietal Information Program for Soybeans (VIPS), *Phil Orwick* |
| 1:30 p.m. | Illinois SCN Coalition: The Final Report But Not the Final Chapter, *Rebecca Richardson* |
| 1:45 p.m. | Soybean Cyst Nematode: The Race is Off, *Terry Niblack* |
| 2:00 p.m. | Panel Discussion |

**Symposium B: New Innovations in Weed Science** - Illini Room B (1.2 CCA credits in Pest Management)
*Aaron Hager and George Soltwedel, Moderators*

| | |
|---|---|
| 1:00 p.m. | Assessing Corn Hybrid Sensitivity to Herbicides, *Brent Tharp* |
| 1:15 p.m. | Common Waterhemp Resistance to PPO Inhibiting Herbicides, *Dallas Peterson* |
| 1:30 p.m. | Dealing with Common Pokeweed in No-Till Corn and Soybean Production, *J.D. Green* |
| 1:45 p.m. | WeedSOFT: A New Approach to Weed Management Decisions, *Christy Sprague* |
| 2:00 p.m. | Panel Discussion |

**Seminars 1–5 run concurrently with Symposia A and B from 1:00–2:30 p.m.**

**Seminar 1: Insect Vectors of Plant Pathogens** - Room 314B - *David Ragsdale*

When insects, weeds, and diseases combine forces, the results can be disastrous. Learn how insects serve as vectors of diseases and how alternate hosts may play an important role in the transmission. (1.5 CCA credits in Pest Management)

**Seminar 2: Soil and Herbicide Interactions** - Room 314A - *Bill Simmons*

Soil-applied herbicides and post-emergence herbicides with soil activity are important parts of weed management systems. Learn how application timing, weather, and soil conditions affect herbicide efficacy. What is the potential carryover or crop response to soil applied herbicides? This session offers a comprehensive review of how current commercially-used corn and soybean herbicides behave in the soil. (1.5 CCA credits in Pest Management)

**Seminar 3: Drainage Management for Water Quality and Crop Production Benefits** - Room 407 - *Don Pitts*

This presentation will describe how drainage management can provide water quality and agriculture production benefits. Hydrology principles, field experiences, and computer simulations will be used to show how drainage management can decrease nitrate loading to streams and decrease water stress to crops during dry periods. (1.5 CCA credits in Soil & Water Managment)

**Seminar 4: Gaining Perspective on Biotechnology Driven Seed Issues** - Room 404 - *Dennis Thompson and Doug Miller*

This session will address primary seed certification systems utilized in the U.S. and the adventitious presences of genetically modified materials in conventionally developed seed. A report based on an industry-wide research effort regarding seed corn pollen issues, considerations for developing identity preserved grain systems, and practical applications based on the principals of seed certification will be discussed. (1.5 CCA credits in Crop Production)

**Seminar 5: Digital Imaging: Get the Right Picture** - Room 405 - *Dennis Bowman and Robert Bellm*

The use of digital cameras, e-mail and the Internet have streamlined the pest diagnosis process. This workshop will focus on identification of crop plant, insect, weed, and disease traits that are critical for accurate diagnosis. (1.5 CCA credits in Pest Management)

2:30-3:00 p.m. **Break** - Illini Room C and Room 406

**Symposia A and B and Seminars 1-5 are repeated concurrently from 3:00-4:30 p.m.**

**Symposium A (repeated): Plant Disease** - Illini Room A

**Symposium B (repeated): New Innovations in Weed Science** - Illini Room B

**Seminar 1 (repeated): Insect Vectors of Plant Pathogens** - Room 314B

**Seminar 2 (repeated): Soil and Herbicide Interactions** - Room 314A

**Seminar 3 (repeated): Drainage Management for Water Quality and Crop Production Benefits** - Room 407

**Seminar 4 (repeated): Gaining Perspective on Biotechnology Driven Seed Issues** - Room 404

**Seminar 5 (repeated): Digital Imaging: Get the Right Picture** - Room 405

5:00-7:00 p.m. **IFCA Sponsored Mixer** - Illini Union Ballroom
*This mixer is sponsored by the Illinois Fertilizer and Chemical Association, and it is intended for everyone to meet with speakers, sponsors, and committee members in an informal atmosphere.*

## WEDNESDAY MORNING, JANUARY 9

**Symposia C and D run concurrently with Seminars 6-10 from 8:00-9:30 a.m.**

**Symposium C: Insects of 2001** - Illini Room A
(1.2 CCA credits in Pest Management)
*Joseph Spencer and Paul Vassalotti, Moderators*

8:00 a.m. Understanding Armyworm Outbreaks: Echoes from the Past, *Rick Weinzierl*

8:15 a.m. Awesome Aphids - *Aphis glycines* in Michigan in 2001, *Christina DiFonzo*

8:30 a.m. Western Corn Rootworms: Strange Tales in 2001 and Management Options for 2002 (and Beyond), *Kevin Steffey*

8:45 a.m. White Grubs: A Tale of Three Rasters, *Larry Bledsoe*

9:00 a.m. Panel Discussion

**Symposium D: Regulatory Issues** - Illini Room B
(1.2 CCA credits in Pest Management)
*Michael Rahe and Dave Feltes, Moderators*

8:00 a.m. Labels, Science, and Reality, *Fred Whitford*

8:15 a.m. EPA Rules: From Regulators to Applicators, Where Do We Go From Here? *John Ward*

8:30 a.m. Invasive Species: What Are They? *Stan Smith*

8:45 a.m. Illinois Noxious Weed Law: A Quandary of Enforcement, *Tom Walker*

9:00 a.m. Panel Discussion

**Seminars 6–10 run concurrently with Symposia C and D from 8:00–9:30 a.m.**

**Seminar 6: Soybean Disease Update: An Overview of Important Soybean Diseases and Results of Current Research Efforts** - Room 404 - *Darin Eastburn and Brian Diers*

This session will focus on important soybean diseases of Illinois. It will include an overview of identification and biology of these diseases, as well as a discussion of current management recommendations. Current research projects will be described, including efforts to breed disease-resistant lines. (1.5 CCA credits in Pest Management)

**Seminar 7: Phytophthora Diseases of Illinois Crops** - Room 209 - *Dean Malvick and Mohammad Babadoost*

Diseases of Illinois vegetable and field crops, caused by various Phytophthora pathogens, can be serious threats to crop production. The causes and conditions favoring Phytophthora diseases of alfalfa, cucurbits, eggplants, peppers, soybeans, and tomatoes will be described, and effective methods for management of these diseases will be discussed. (1.5 CCA credits in Pest Management)

**Seminar 8: Organic Matter Management and Carbon Sequestration** - Room 314B - *Michelle Wander*

This session will address why and how interest in soil organic matter management and carbon sequestration has grown during the last few years. Relevant research, programs, and policy happenings will be discussed. (1.5 CCA credits in Soil & Water Management)

**Seminar 9: Three Certainties in Life: Death, Taxes, and Weeds** - Room 314A - *Jerry Doll, Loyd Wax and Aaron Hager*

Changes in the weed spectrum frequently lead to additional management difficulties. These changes may be caused by the presence of weed species not previously considered problematic, or by changes in the biology of more familiar species. This session will discuss changes in the emergence characteristics of giant ragweed, biology and management of hophornbeam copperleaf, and characteristics of weed species such as teasel and wild four-o'clock. (1.5 CCA credits in Pest Management)

**Seminar 10: Using Herbicide Mode of Action to Improve Crop Diagnostic Skills** - Room 405 - *Jeff Gunsolus*

Knowledge of a herbicide's mode of action can be advantageous when planning a weed management strategy. The creator of the CD "Herbicide Mode of Action and Crop Injury Symptoms" will lead the participants through this CD. Various modes of actions will be covered on this CD with more than 500 photos and images on herbicide symptomology. This session will also cover crop injury symptoms, with time-lapse video clips, that can sometimes be caused by these herbicides. (1.5 CCA credits in Pest Management)

9:30–10:00 a.m. **Break** - Illini Room C and Room 406

**Symposia C and D and Seminars 6–10 are repeated concurrently from 10:00–11:30 a.m.**

**Symposium C (repeated): Insects of 2001** - Illini Room A

**Symposium D (repeated): Regulatory Issues** - Illini Room B

**Seminar 6 (repeated): Soybean Disease Update: An Overview of Important Soybean Diseases and Results of Current Research Efforts** - Room 404

**Seminar 7 (repeated): Phytophthora Diseases of Illinois Crops** - Room 209

**Seminar 8 (repeated): Organic Matter Management and Carbon Sequestration** - Room 314B

**Seminar 9 (repeated): Three Certainties in Life: Death, Taxes, and Weeds** - Room 314A

**Seminar 10 (repeated): Using Herbicide Mode of Action to Improve Crop Diagnostic Skills** - Room 405

11:30 a.m.–1:00 p.m. **Lunch**

## WEDNESDAY AFTERNOON, JANUARY 9

**Symposia E and F run concurrently with Seminars 11–15 from 1:00–2:30 p.m.**

**Symposium E: Soil and Water** - Illini Room A
(1.2 CCA credits in Soil & Water Management)
*Dennis Epplin and Steve Barrett, Moderators*

| | |
|---|---|
| 1:00 p.m. | The Illinois Nitrogen Soil Test, *Robert Hoeft* |
| 1:15 p.m. | TMDLs and Other Alternatives, *George Czapar* |
| 1:30 p.m. | Effect of Tile Depth on Nitrate Transport from Tile Drainage Systems, *Richard Cooke* |
| 1:45 p.m. | Soils and Water: On-Farm Trial Results, *Emerson Nafziger* |
| 2:00 p.m. | Panel Discussion |

**Symposium F: Biotechnology - Illini Room B**
(1.2 CCA credits in Pest Management)
*Dan Zinck and A.G. Taylor, Moderators*

| | |
|---|---|
| 1:00 p.m. | Biotechnology: The Future for Corn, *Randy Krotz* |
| 1:15 p.m. | Biotechnology Patent Issues: An Industry Perspective, *Jim Shearl* |
| 1:30 p.m. | Biotechnology: Expanding the Biofuel Industry, *Michael Cotta* |
| 1:45 p.m. | Biotechnology: The Good, the Bad, and the Ugly, *David Lightfoot* |
| 2:00 p.m. | Panel Discussion |

**Seminars 11–15 run concurrently with Symposia E and F from 1:00–2:30 p.m.**

**Seminar 11: What Do We Know About Grape Colaspis?** - Room 209 - *Michael Roegge, Matthew Montgomery, Randall Wright*

Until recently, grape colaspis was considered a sporadic pest with injury rarely occurring in corn planted after alfalfa and soybeans, but damage from this pest is now occurring frequently in both corn and soybean fields. Following a brief overview of the life cycle of grape colaspis, 2001 data from field research and insecticide efficacy trials will be discussed. (1.5 CCA credits in Pest Management)

**Seminar 12: New Directions in Scouting for Soybean Cyst Nematode (SCN)** - Room 314B - *Terry Niblack and Greg Tylka*

Big changes are in the works regarding how we assess soybean cyst nematode (SCN) populations. From initial assessment to monitoring SCN numbers and "races" over time, our methods and interpretations will be different in the future. We invite you to come and learn about these changes and how they may impact your approach to SCN assessment and management. (1.5 CCA credits in Pest Management)

**Seminar 13: So You Think You Have a Herbicide Resistant Pigweed?** - Room 314A - *Aaron Hager and Patrick Tranel*

Herbicide resistant weed biotypes continue to be problematic for corn and soybean producers. Leading the way are various pigweed species that have developed resistance to more than one herbicide mode of action. If you have problems controlling a weed with a particular herbicide and suspect resistance, how do researchers determine if herbicide resistance has indeed developed? This session will focus on the current status of herbicide resistant weed biotypes in Illinois, with particular emphasis on herbicide resistance in various pigweed species, and describe the experimentation (including molecular biology techniques) researchers use to confirm herbicide resistance. (1.5 CCA credits in Pest Management)

**Seminar 14: Formulations and Calculations - What Does It All Mean?** - Room 404 - *Jeffrey Bunting, Lawrence Steckel, and Christy Sprague*

Determining herbicide calculations can be mind teasing during the busy days of summer. Even more so is the mind confusing herbicide formulations that are in the marketplace. Instructors will provide insight to why herbicides are formulated the way they are and some techniques to use to calculate exactly how much active herbicide is being applied. These calculations can be very useful in comparing different herbicide formulations and premixtures. (1.5 CCA credits in Pest Management)

**Seminar 15: Western Corn Rootworm: New Insights to an Old Problem** - Room 405 - *Timothy Mabry, Christopher Pierce, and Matthew O'Neal*

Crop phenology and adult feeding preferences play an important role in the behavior of rotation resistant western corn rootworms. Laboratory and field trials conducted during 2001 in Michigan and Illinois that examined WCR distribution, emergence, migration, and egg-laying have provided new insights to this old problem. (1.5 CCA credits in Pest Management)

2:30-3:00 p.m. **Break** - Illini Room C and Room 406

**Symposia E and F and Seminars 11–15 are repeated concurrently from 3:00–4:30 p.m.**

**Symposium E (repeated): Soil and Water** - Illini Room A

**Symposium F (repeated): Biotechnology** - Illini Room B

**Seminar 11 (repeated): What Do We Know About Grape Colaspis?** - Room 209

**Seminar 12 (repeated): New Directions in Scouting for Soybean Cyst Nematode (SCN)** - Room 314B

**Seminar 13 (repeated): So You Think You Have a Herbicide Resistant Pigweed?** - Room 314A

**Seminar 14 (repeated): Formulations and Calculations - What Does It All Mean?** - Room 404

**Seminar 15 (repeated): Western Corn Rootworm: New Insights to an Old Problem** - Room 405

4:30 p.m. **Adjournment**

# Program Participants

**Babadoost, Mohammad.** Assistant Professor and Extension Specialist for Fruit and Vegetable Pathology, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL.

**Barrett, Steve.** Galesville Chemical Co., Galesville, IL

**Bellm, Robert.** Extension Educator - Crop Systems, Edwardsville Extension Center, University of Illinois, Edwardsville, IL.

**Bissonnette, Suzanne.** Extension Educator - Integrated Pest Management, Champaign Extension Center, University of Illinois Extension, Champaign, IL.

**Bledsoe, Larry.** Pest Management Area Specialist, Department of Entomology, Purdue University, West Lafayette, IN.

**Bond, Jason.** Assistant Professor, Department of Plant, Soil, and General Agriculture, Southern Illinois University, Carbondale, IL.

**Bowman, Dennis.** Extension Educator - Crop Systems, Champaign Extension Center, University of Illinois Extension, Champaign, IL.

**Bunting, Jeffrey.** Graduate Research Assistant, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL.

**Conklin, Neil.** Director, Marketing and Trade Economics Division, USDA, Economic Research Service, Washington, D.C.

**Cooke, Richard.** Associate Professor, Department of Agricultural Engineering, University of Illinois, Urbana-Champaign, IL.

**Cotta, Michael.** ARS Microbiologist, United States Department of Agriculture-ARS, Peoria, IL.

**Czapar, George.** Extension Educator - Integrated Pest Management, Springfield Extension Center, University of Illinois Extension, Springfield, IL.

**Diers, Brian.** Professor, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL.

**DiFonzo, Christina.** Field Crops Entomologist and Pesticide Education Coordinator, Michigan State University, East Lansing, MI.

**Doll, Jerry.** Professor, Department of Agronomy, University of Wisconsin, Madison, WI.

**Eastburn, Darin.** Professor, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL.

**Epplin, Dennis.** Extension Educator - Crop Systems, University of Illinois Extension, Mt. Vernon, IL.

**Feltes, Dave.** Extension Educator - Integrated Pest Management, University of Illinois Extension, East Moline, IL.

**Gianessi, Leonard.** National Center for Food and Agriculture Policy, Washington, D.C.

**Gleason, Todd.** Media Communications Specialist, Information Technology and Communication Services, University of Illinois, Urbana-Champaign, IL.

**Green, J.D.** Extension Weed Scientist, Department of Agronomy, University of Kentucky, Lexington, KY.

**Gunsolus, Jeff.** Professor and Extension Agronomist - Weed Science, Department of Agronomy, University of Minnesota, St. Paul, MN.

**Hager, Aaron.** Extension Specialist in Weed Science, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL.

**Hoeft, Robert.** Professor and Extension Specialist, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL.

**Krotz, Randy.** Director of Industry Affairs, Monsanto, St. Louis, MO.

**Lightfoot, David.** Associate Professor, Department of Plant, Soil, and General Agriculture, Southern Illinois University, Carbondale, IL.

**Mabry, Timothy.** Graduate Research Assistant, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL.

**Malvick, Dean.** Assistant Professor and Extension Specialist for Field Crop Pathology, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL.

**Miller, Doug.** Director of Field Services, Illinois Crop Improvement Association, Inc., Champaign, IL.

**Montgomery, Matthew.** Unit Educator - Crop Systems, Sangamon/Menard Extension Unit, University of Illinois Extension, Springfield, IL.

**Nafziger, Emerson.** Professor, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL.

**Niblack, Terry.** Professor, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL.

**O'Neal, Matthew.** Graduate Research Assistant, Department of Entomology, Michigan State University, East Lansing, MI.

**Orwick, Phil.** Special Projects Coordinator, National Soybean Research Center, University of Illinois, Urbana-Champaign, IL.

**Peterson, Dallas.** Extension Weed Specialist, Kansas State University, Manhattan, KS.

**Pierce, Christopher.** Graduate Research Assistant, Department of Entomology, University of Illinois, Urbana-Champaign, IL.

**Pitts, Don.** Water Quality Specialist, Natural Resources Conservation Service, United States Department of Agriculture, Champaign, IL.

**Ragsdale, David.** Professor, Department of Entomology, University of Minnesota, St. Paul, MN.

**Rahe, Michael.** Sustainable Agriculture Representative, Illinois Department of Agriculture, Springfield, IL.

**Ratcliffe, Susan.** Extension Specialist, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL.

**Richardson, Rebecca.** Director of Operations, Illinois Soybean Association, Bloomington, IL.

**Roegge, Michael.** Unit Educator - Crop Systems, Adams/ Brown Extension Unit, University of Illinois Extension, Quincy, IL.

**Shearl, Jim.** Executive Vice President, Golden Harvest Seeds Inc., Bloomington, IL.

**Simmons, F. William.** Associate Professor, Department of Natural Resources and Environmental Sciences, University of Illinois, Urbana-Champaign, IL.

**Smith, Stan.** Manager, Nursery and Northeast Field Operations, Illinois Department of Agriculture, Des Plaines, IL.

**Soltwedel, George.** Crop Sales Specialist, Effingham Equity, Altamont, IL.

**Sonka, Steven.** Professor and Director of National Soybean Research Laboratory, University of Illinois, Urbana-Champaign, IL.

**Spencer, Joseph.** Assistant Professional Scientist, Illinois Natural History Survey, Urbana-Champaign, IL.

**Sprague, Christy.** Assistant Professor and Extension Weed Specialist, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL.

**Steckel, Lawrence.** Graduate Research Assistant, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL.

**Steffey, Kevin.** Professor and Extension Specialist, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL.

**Taylor, A.G.** Agricultural Advisor, Environmental Policy, Illinois Environmental Protection Agency, Springfield, IL.

**Tharp, Brent.** Research Agronomist, Golden Harvest Seeds Inc., Cordova, IL.

**Thompson, Dennis.** Chief Executive Officer, Illinois Crop Improvement Association, Inc., Champaign, IL.

**Tranel, Patrick.** Assistant Professor, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL.

**Tylka, Greg.** Professor, Nematology, Iowa State University, Ames, IA.

**Vassalotti, Paul.** BASF, Cross Plains, WI.

**Walker, Tom.** Manager, Support Services, Bureau of Environmental Programs, Illinois Department of Agriculture, Springfield, IL.

**Wander, Michelle.** Associate Professor, Department of Natural Resources and Environmental Sciences, University of Illinois, Urbana-Champaign, IL.

**Ward, John.** Section Chief, US EPA Region 5 Pesticide Programs, Chicago, IL.

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# Transgenic Technology: A Crop Protection Bargain?

LEONARD GIANESSI

Genetically engineered crop cultivars have been planted on millions of acres of U.S. soybean, field corn, canola, and cotton. Such cultivars have been engineered to be herbicide tolerant or insecticidal and thus to offer pest management benefits. Growers choose to plant these cultivars instead of conventional cultivars because they provide more effective or less expensive pest control. Soybean farmers have planted herbicide-tolerant cultivars because then they can use a less expensive herbicide and still realize the same level of broad-spectrum control as was previously achieved with combinations of three or four herbicides. It is estimated that soybean growers have saved approximately $200 million/year in reduced herbicide expenditures by planting herbicide-tolerant cultivars, and the percentage of soybean acreage planted with transgenic herbicide-tolerant cultivars increases each year.

A majority of the nation's canola acres is planted with transgenic, herbicide-tolerant cultivars because the herbicide glyphosate provides significantly better control than alternative herbicides. Herbicide-tolerant cotton acreage continues to expand. Previously available postemergence herbicides could not be safely used over the top in cotton. Cotton growers relied on post-directed herbicide applications and numerous cultivation trips. The adoption of herbicide-tolerant biotech cotton has resulted in significant reductions in weed control costs, including reductions in tillage, and in the number of active ingredients applied.

Benefits from planting transgenic insecticidal field corn have been more problematic. Insecticidal field corn cultivars express a pŠrotein from the soil microorganism *Bacillis thuringiensis* (Bt), which kills the European corn borer when it feeds on the plant. Before the introduction of the Bt field corn, the European corn borer was estimated to destroy $1 billion of corn each year. In 1997, European corn borer populations were about average and it was estimated that growers who planted Bt corn gained approximately $18/acre in income after covering the technology fee. A strange thing has happened since then–populations of the European corn borer throughout the Corn Belt have been at historically low levels for 4 yr. As a result, growers have not experienced the same yield increase. With the precipitous drop in the price of corn, the financial gain associated from planting Bt corn does not cover the technology fee, on average. Is it a coincidence that European corn borer populations have plummeted following the widespread planting of Bt corn? Will populations go back to previous levels? All we know is that fewer farmers are planting Bt corn because the economic payoff has not been there.

The same phenomenon is occurring in the southeastern United States with Bt cotton, which controls bollworms and budworms. Although the initial benefits were high in Alabama, they have dropped off in recent years. Indeed, Monsanto's own publicly released data indicate that southeastern Bt cotton growers gained $38/acre in 1998 but just $3/acre in 2000. The reason is greatly reduced populations of budworm and bollworm.

There are great expectations for the introduction of Bt corn, which controls rootworm. Several products are in commercial development. It is widely assumed that the introduction of rootworm-resistant seed will result in growers stopping their current practice of applying at-plant soil insecticides, which will depend on how the technology is priced and how effective the seed treatments are for other pests such as cutworms and wireworms that are also currently controlled with the rootworm insecticide. Will manufacturers of rootworm insecticides lower their prices to stay competitive?

Not all commercially available insecticidal and herbicide-tolerant crop cultivars have been planted in the United States, even though their planting would deliver signifi-

cant financial advantages to growers. Because of the controversy surrounding genetic engineering, many large food companies have informed growers that certain genetically engineered crop cultivars are not acceptable. French fry companies would not accept potatoes that had been engineered to resist the Colorado potato beetle feeding and to resist viruses spread by aphids. If U.S. potato growers had planted these cultivars insecticide use on potato acreage would have declined by approximately 50% with improved yields and net returns for growers.

The U.S. sugar beet growers are not planting a herbicide-tolerant cultivar that has been approved by United States regulatory agencies and commercialized because no sugar processor has listed the cultivar as acceptable due to concerns expressed by sugar buyers, including candy manufacturers. Probably every sugar beet grower in the United States would plant the transgenic cultivar and switch away from current weed control practices, which typically include four herbicide applications of four active ingredients, three to four cultivation trips, and 8 h of handweeding per acre. The transgenic weed control technology would save the average grower approximately $75/acre. On average, sugar beet growers are losing $30-40/acre. Thus, growers are being denied the use of a technology that would turn their crop into a profitable one.

Many additional crops are in the research and development pipeline–nematode-resistant pineapple, bacteria-resistant apples, virus-resistant citrus, and fungus-resistant sunflowers–to name a few. These biotech crops are being developed by university and federal laboratories to address serious local pest management needs. Commercial development is proceeding with development of herbicide-tolerant transgenics for large-acreage crops such as wheat, alfalfa, rice, and sugarcane. In all these cases the transgenic crop would offer growers the opportunity of significantly lowering weed control costs. Opposition already exists to these crops. Even if approved, farmers may not get to plant them because of vocal opposition, concern over brand names, and potential for export losses.

One of the great potentials for biotechnology is the development of transgenic cultivars that improve the management of pests. Significant advances have been made in developing cultivars that resist insects, viruses, nematodes, fungi, and bacteria or that permit the use of effective, inexpensive, broad-spectrum herbicides. Growers no longer necessarily get to choose the pest control material that optimizes their operations. Rather "consumers" get to decide. In most cases it isn't the consumer in the supermarket who opposes biotech crops–the opposition and nervousness is coming from large corporate buyers who do not necessarily have the best interests of U.S. growers foremost in their plans.

# Globalization, Technology and Agriculture

**STEVE SONKA**

Those of us who've had the good fortune to live and work over the past two or three decades have experienced and participated in a truly revolutionary time of economic advance. This experience, which was complex and uncertain, is now referred to by the all-purpose term globalization. "Globalization, we believe, is the most important phenomenon of our time" (Micklethwait and Wooldridge, 2000). As with many such phenomena, the popular press and much of society associate an extraordinary set of positive and negative features with this term. In the latter part of the 1990s, the conventional wisdom became that globalization was an "unstoppable" force that would shape the future of society. Furthermore, economic historians and pundits could provide reasoned analyses, based upon theory and extensive references, proving that the historic march to globalization had been both predictable and certain.

This article explores globalization and its implications for agriculture's future. It is divided into four sections. In the first section, I attempt to develop a solid understanding of globalization and the forces that have led to our current status. In the second section, I examine the major effect of globalization for agriculture, that is, its role in creating economic growth. Historically, globalization often was perceived as primarily being about trade. Today, however, direct investment and technology transfer are critical components of globalization and are covered in the third section of this article. The concluding section focuses on the notion of globalization as a powerful, but not preordained, social force.

## THIS THING CALLED GLOBALIZATION

Globalization has become one of those terms that is immediately recognized but whose meaning is not necessarily commonly understood. Integration across national boundaries is a key part of any definition of globalization. But this integration extends beyond economics to include culture and social "homogenization." And this integration can extend across cultures and societies as well as nations. The powerful potential reach of globalization provides a partial explanation for the passionate opposition to globalization held by small minorities. The power to exercise control is challenged by the forces underlying globalization.

Philosophically, globalization reduces one of the most basic historic truths of human existence, the tyranny of the place. For much of human history, the scope of an individual's understanding and opportunity was fundamentally linked to where they were born. But the tyranny of the place is not just applicable to where people live. Instead, humans were fundamentally limited in terms of the following: where they could go; what they could buy; where they could invest; and what they could read, hear, and see. With globalization, the power to choose has come to individuals, providing choice sets that historically had not been available to the individual. Instead, these choices had been the province of governments, social institutions, and cultural traditions. Although this expansion of choice set is excitingly liberating, it also has side effects that are profoundly frightening.

Globalization is not the product of any single phenomenon; instead, globalization is the complex result of massive changes in technology, in how investment occurs, and in how individuals learn about their local and global circumstances. Capitalism and the market economy are intertwined with globalization. Of these two phenomena, it is not clear which is cause and which is effect. But they are interlinked.

Communications technology has been a core force for change. Friedman (1999) provides an intriguing illustra-

tion of the change in communications capabilities that we now take for granted. The story involves Larry Summers, who served as Deputy U.S. Treasury Secretary in the Clinton administration. Before the Clinton administration, Summers had worked in the Dukakis 1988 presidential campaign and while traveling in Chicago, he actually rode in a car with a phone in it. He found this technological feat so amazing that he called his wife just to tell her about it. In 1997, while traveling for the U.S. Treasury Department, Summers visited a remote village in the Ivory Coast to celebrate the drilling of the first well in this village with potable drinking water. As he exited the canoe that brought him to the village, an Ivory Coast official handed him a cell phone because Washington wanted to ask him a question–and Summers wasn't surprised. The technological ability to communicate had been profoundly altered in just 9 yr.

Despite the many anecdotes that can be (and have been) offered about the positive features of globalization, recent years have seen intellectual criticism and well-publicized demonstrations opposed to alleged numerous evils of globalization. It is appropriate for differing people to regard the same event differently. For example, information brought by satellite that encourages women in a specific society to question historic cultural norms will be viewed as progress by some but as evil propaganda by others.

Although still controversial in public discourse, the economic effects of globalization are well defined. Let's look briefly at one of the more controversial events associated with globalization, that of the factory that relocates its jobs from a developed nation to a developing nation. The motivation for this relocation is the potential to produce its output at lower cost after trade barriers were reduced between the developed and developing nation. Several effects follow:

- Workers in the developing country will have new jobs. Critics argue that these workers are being exploited because their wages are less than were paid to workers in the developed nation. Others stress that these workers are now receiving higher wages than they would have otherwise.
- Generally, the firms that relocate bring advanced technology, both embodied in machines and in labor skills, which raises the overall manufacturing capabilities within the developing nation. These factors, as well as the direct demand effect of the new jobs, will provide pressure to raise overall wage rates in the developing nation.
- Additional income in the developing nation has important secondary effects. Greater spending increases economic activity throughout that nation's economy, providing economic multiplier effects. Throughout the world, greater income enables parents to invest additional resources in the education and skills of their children. Furthermore, although environmental amenities are appreciated by all people, impoverished people have limited capability to invest in maintaining those amenities. Therefore, income growth in fact tends to be positively related to maintaining natural resources and environmental well being.
- In the developed nation, the workers who previously worked in the displaced factory have lost their jobs. This situation is powerfully negative for these individuals and often on their local communities. The *Economist* magazine (2001) reports on extensive analyses of the *total* impact of these types of events. Overall, the tendency is for the result to be a shift in employment, not a decline or an increase. And, the job lost tends to be a lower wage job than the jobs created in other parts of the economy. However, for the individual displaced the effects can be devastating without compensating social and economic policies.
- A final factor that is often overlooked has to do with consumers. The combination of less costly goods, more efficient economies, and income growth provides more choice to consumers, in both the developed and developing nations.

## GLOBALIZATION: ECONOMIC GROWTH EFFECT

One of the key issues facing agricultural producers in general, and the soybean industry in particular, is uncertainty regarding the future market. To address this concern, we, at National Soybean Research Laboratory, have developed a system dynamics model, the Protein Consumption Dynamics (PCD) model, to explore the potential for global protein appetite in the world food system (Fisher, 2000) (Model development was funded in part by the Illinois Soybean Program Operating Board.) The tool simulates future global protein appetite scenarios based on population and income growth to examine potential future world food needs. The model highlights the systematic relationships between population, income, appetite (potential demand), and malnutrition. It tracks the human appetite for six agricultural commodities (beef, pork, poultry fish, fats, oils, and vegetable protein), on a global basis, annually for the years 2001 to 2025. The model also explores malnutrition for the same time period. Based on model projections, the future market for soybean and other commodities

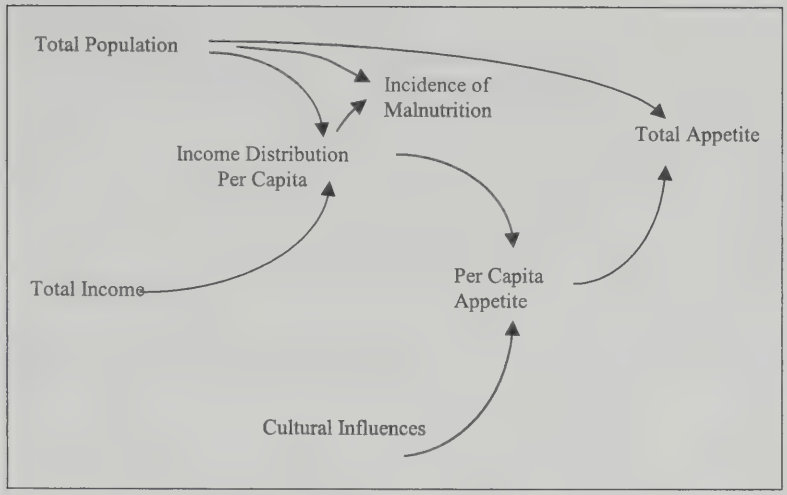


**Figure 1. Relationships underlying the protein consumption dynamics model.**

could be dramatically different from the market experienced over the past few decades.

## Model Structure

Figure 1 illustrates the relationships made explicit in the PCD model. On a region-by-region level, the model determines the per capita appetite for various commodities then aggregates to get the total potential demand for the commodities by region and in total. In the PCD model, a region's income and population increase each year based on specified rates from the aforementioned data. The effects of cultures and dietary preferences are reflected in the regionally specific econometric estimates between income and food appetite. The effects of per capita income and cultural influences are combined to develop estimates of appetite (potential demand or consumption) and malnutrition for each region. These per capita estimates are then multiplied by the appropriate population estimates for each region to compute total potential demand for the various commodities.

**Table 1. PCD regional definitions.**

| |
|---|
| China |
| East Asia |
| Transition Economies |
| Latin America |
| Middle East and North Africa (MENA) |
| OECD (The relatively economically well-off nations of Europe, North America, and Japan) |
| South Asia |
| Sub-Saharan Africa |

Cultural differences are incorporated through the identification of eight demographic regions. For this analysis, the regions are defined to be relatively homogeneous in terms of income, income growth levels, food appetite patterns, and cultural characteristics. These regions, which are consistent with those identified by both the World Bank and the United Nations Food and Agriculture Organization (UN FAO), are delineated in Table 1.

A key reason for the development of this modeling capability is to explore a range of parameter values. Therefore, the capability to compare the effects of alternative assumptions on the desire and need for protein *across* a range of parameter values is important. To illustrate this capability, two future scenarios are defined:

- *Base Case:* uses population growth projections consistent with World Bank and UN FAO medium-level projections and income growth projections consistent with the actual experience of the past two decades.
- *Lower Income Case:* uses the population projections of the Base Case and income growth rates that are 50 % smaller than those of the Base Case.

These scenarios are projections as defined by Ferris (1998). For the purposes of this article, the probability of each scenario occurring is not important; the bigger concern is with getting decision makers to consider alternative potential futures rather than predict the future. The model framework requires that future income and population growth be projected for each region. Population and income growth information are based on secondary data taken from the World Bank and the FAO. The historic consumption data are taken from the FAOSTAT Statistical Database 1997. Historic and future malnutrition data are taken from FAO and Bread for the World (BFW 1998). More information on malnutrition can be found at http://www.fao.org/NEWS/1999/991004-e.htm

It is difficult to find long-term income growth rate projections from official sources. The income projections used herein (Table 2) are based upon historic rates of income growth, published literature on future prospects (Coplin and O'Leary, 1994), and expert judgment.

## Modeling Results

This section describes the modeling results provided by the PCD model. The information provided is only a small

**Table 2. Annual income growth rates.**

| Regions | Historic[a] (%) | Base Case (%) | Lower Income (%) |
|---|---|---|---|
| China | 10.20 | 9.00 | 4.50 |
| East Asia | 7.00 | 6.00 | 3.00 |
| Transition Economies | –0.50 | 1.60 | 0.80 |
| Latin America | 2.20 | 2.20 | 1.10 |
| MENA | –1.40 | 1.00 | 0.50 |
| OECD | 2.60 | 2.60 | 1.30 |
| South Asia | 5.60 | 5.40 | 2.70 |
| Sub-Saharan Africa | 1.50 | 2.00 | 1.00 |
| World | 3.40 | 3.70 | 1.90 |

[a] Historic annual income growth rates are averages from 1984 to 1996.

subset of data that the modeling tool can provide. A more complete analysis is available in Fisher (2000). For the base case scenario, Figures 2 and 3 show the estimates of total population and per capita income for the years 2001 and 2025 for each of the regions. Although the numbers have profound implications for many measures of human well being, the estimates are probably not too surprising. Population growth is relatively low in the OECD region and the transition economies, roughly 5% for both regions. Conversely, Figure 2 shows relatively high population growth in the MENA and sub-Saharan Africa regions; an increase of >50% for both.

Based upon these assumptions, very strong per capita income growth would occur in China (585%), East Asia (209%), and South Asia (163%) (Figure 3). The growth trajectory for OECD is not included in Figure 3 so as to highlight the variation in the other regions. Income growth in the OECD countries is roughly equal to the global average but starts at a very large initial level. Growth in total gross domestic product (GDP) is weak in the regions with high population growth. The result is a decline in per capita income for the sub-Saharan Africa and MENA regions, -3 and -17%, respectively.

Table 3 indicates how the forces shown in Figures 2 and 3 could impact the appetite for animal protein, fish, and vegetable protein. Globally, the appetite for animal protein increases by 81%, fish by 86%, and vegetable protein by 38%. China, East Asia, and South Asia show large increases in the appetite for animal protein, 146, 213, and 745%, respectively. Appetite growth in the OECD is relatively modest, 7% for animal protein, -1% for fish, and -17% for vegetable protein. These numbers reflect that the OECD countries, in general, will not devote a significant portion of any additional income to expenditures for food. It should be noted, however, that even though the OECD had the smallest level of change in the appetite for animal protein, the region still accounts for nearly 20% of the total appetite (Fisher, 2000).

Over the past three decades, both the number and the proportion of the globe's undernourished population have declined. Table 4 indicates that at the global level, continuation of this trend is possible, with the population and income parameters in Figures 2 and 3. Unfortunately, this relatively positive average number of undernourished at the global level masks serious regional problems,

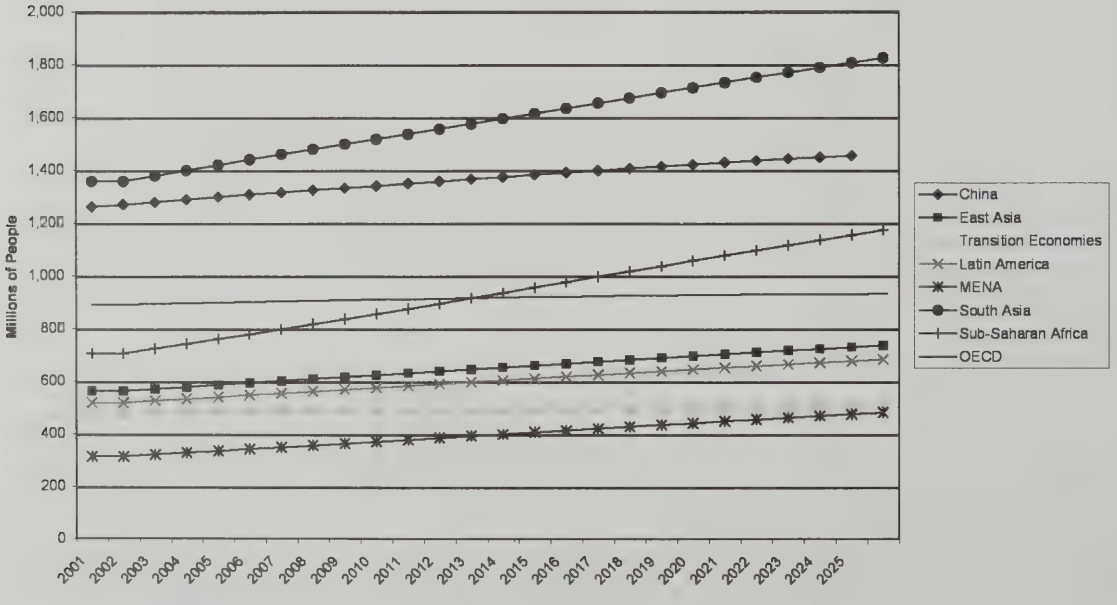


**Figure 2. Population growth: base case 2001 to 2025.**

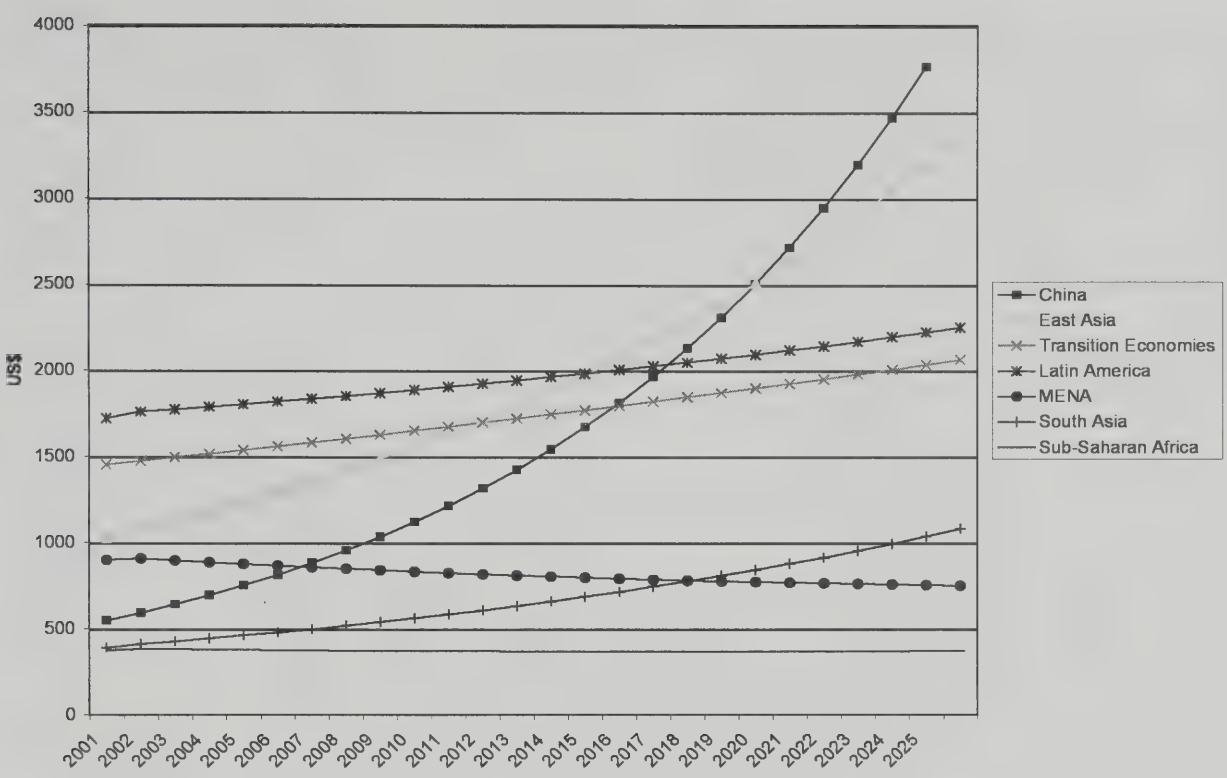


**Figure 3. Per capita income growth: base case 2001 to 2025.**

especially in sub-Saharan Africa and MENA, with increases in the number malnourished of 78 and 97%, respectively. By the 2025, sub-Saharan Africa would account for 56% of the world's malnutrition.

For the lower income scenario, the annual income growth rates are reduced by 50% from their level in the base case scenario. The result is less income spread across the same number of people as in the base case scenario. Figures 4-6 show the comparison in the estimated appetite for the various commodities (animal protein, fish, and vegetable protein, respectively) between scenarios. Each figure shows the appetite for a given commodity for the base case and the lower income scenarios in the year 2025.

The transition economies, Latin America, MENA, and sub-Saharan Africa regions all show little variation in the appetite for animal protein between the two scenarios. In contrast, the appetite for animal protein in the other

**Table 3. Base case scenario: animal protein, fish, and vegetable protein in million metric tons (2001–2025).**

| Base Case | Animal Protein | | | Fish | | | Vegetable Protein | | |
|---|---|---|---|---|---|---|---|---|---|
| Region | 2001 | 2025 | Change (%) | 2001 | 2025 | Change (%) | 2001 | 2025 | Change (%) |
| China | 46.1 | 113.7 | 146 | 18.3 | 49.8 | 172 | 5.9 | 9.3 | 57 |
| East Asia | 9.9 | 31.0 | 213 | 11.3 | 23.3 | 107 | 5.7 | 8.2 | 44 |
| Trans. Econ. | 21.9 | 27.3 | 24 | 4.7 | 6.0 | 28 | 2.1 | 2.6 | 23 |
| Lat. America | 24.8 | 35.7 | 44 | 4.8 | 7.4 | 54 | 6.1 | 7.8 | 28 |
| MENA | 5.1 | 6.5 | 27 | 1.8 | 2.3 | 27 | 3.1 | 4.9 | 58 |
| OECD | 73.7 | 79.1 | 7 | 29.6 | 29.2 | –1 | 8.9 | 7.4 | –17 |
| South Asia | 5.4 | 45.7 | 745 | 6.6 | 27.1 | 310 | 17.2 | 24.6 | 43 |
| SS Africa | 6.3 | 10.4 | 64 | 6.7 | 10.9 | 63 | 9.5 | 15.9 | 67 |
| World | 193.3 | 349.3 | 81 | 83.8 | 156.0 | 86 | 58.6 | 80.7 | 38 |

**Table 4. Base case scenario: malnutrition (2001–2025).**

| Base case | No. undernourished (million) | | | Proportion undernourished | | |
|---|---|---|---|---|---|---|
| Region | 2001 | 2025 | Change (%) | 2001 | 2025 | Change (%) |
| China | 182.3 | 9.7 | –95 | 0.15 | 0.01 | –93 |
| East Asia | 78.2 | 34.9 | –55 | 0.15 | 0.05 | –67 |
| Lat. America | 63.4 | 69.0 | 9 | 0.13 | 0.11 | –15 |
| MENA | 25.6 | 50.5 | 97 | 0.09 | 0.11 | 22 |
| South Asia | 275.2 | 134.2 | –51 | 0.22 | 0.08 | –64 |
| SS Africa | 211.6 | 375.9 | 78 | 0.35 | 0.36 | 3 |
| World | 836.4 | 674.2 | –19 | 0.14 | 0.09 | –37 |

regions is more affected by the reduced income. The strong relationship between income and appetite patterns is evidenced by the sharp decline in animal protein appetite for the Asian regions of China, East Asia, and South Asia in the lower income scenario. The appetite for fish exhibits similar patterns (Figure 5).

Cultural differences influence the appetite for vegetable protein between regions. In the lower income scenario, the appetite for vegetable protein increases slightly in Latin America, MENA, OECD, and sub-Saharan Africa, indicating a substitution of vegetable for animal protein.

Finally, a comparison of malnutrition results between the scenarios is needed. Income and population have a strong influence on malnutrition as illustrated in Figure 7. The decrease in income associated with the lower income scenario brings about startling increases in malnutrition in all six regions evaluated. Sub-Saharan Africa accounts for more than one-third of the world's malnutrition with >300 million people underfed even in the base case scenario.

## GLOBALIZATION: IT'S NOT JUST TRADE

Historically, the economics of international relations has focused on trade particularly of commodities. Today,

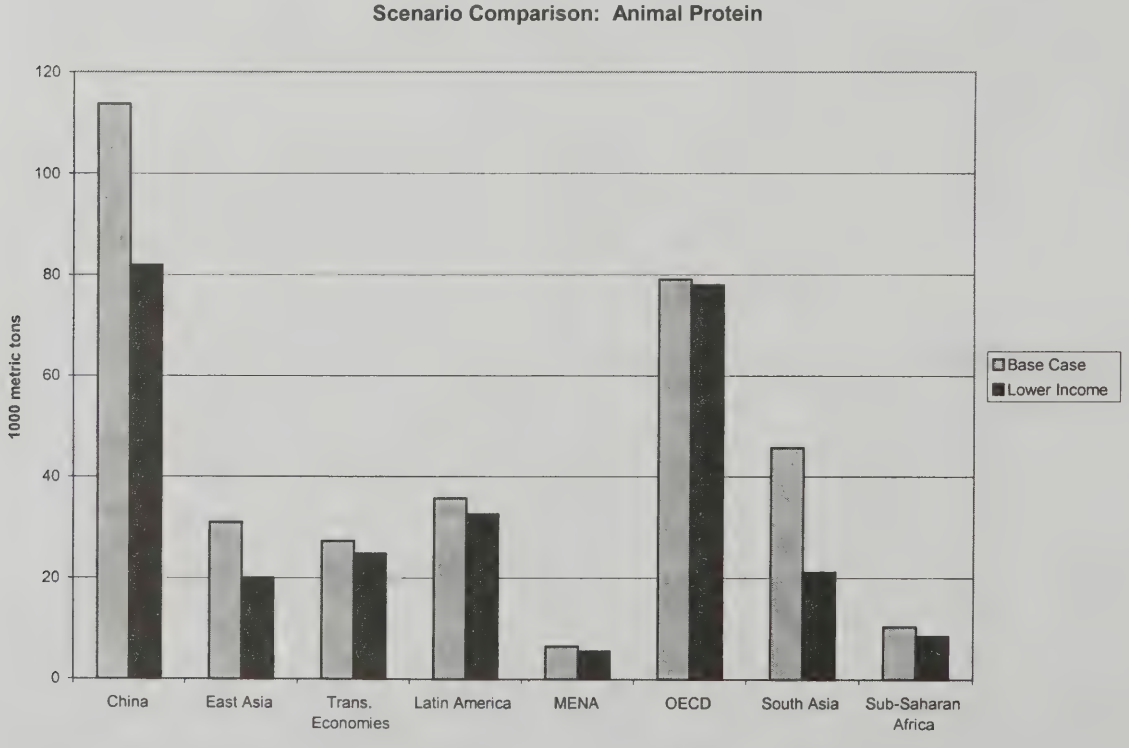


**Figure 4. Scenario comparisons for animal protein appetite in the year 2025.**

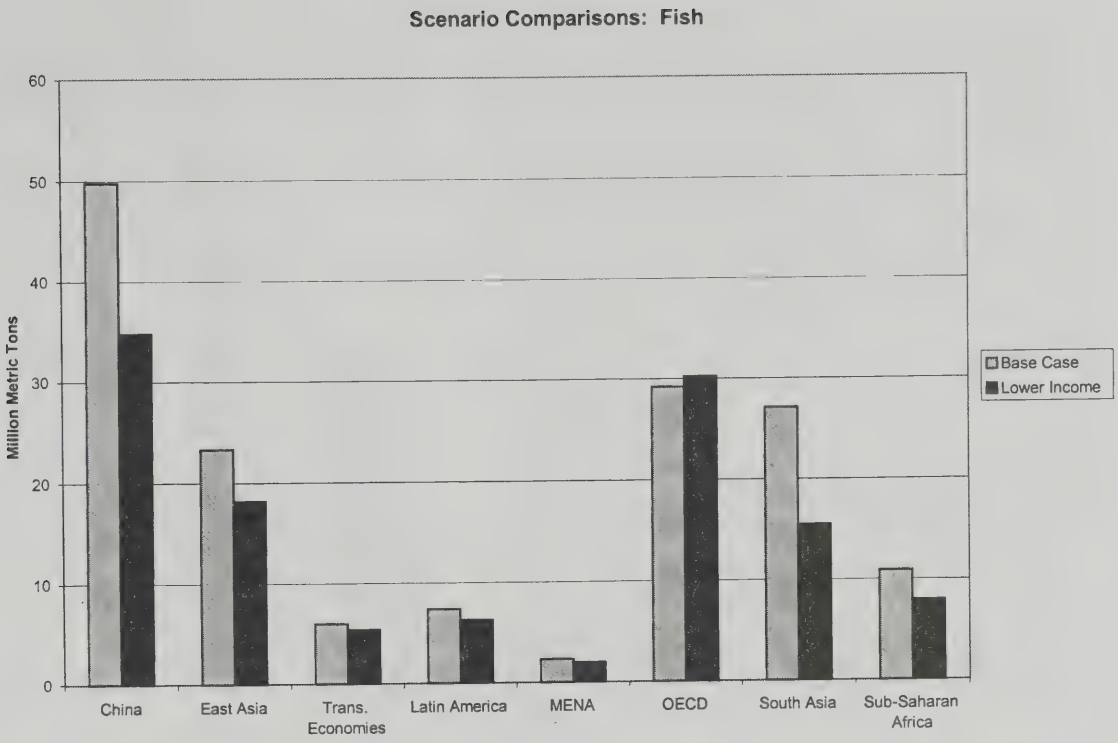


**Figure 5. Scenario comparissons for fish appetite in the year 2025.**

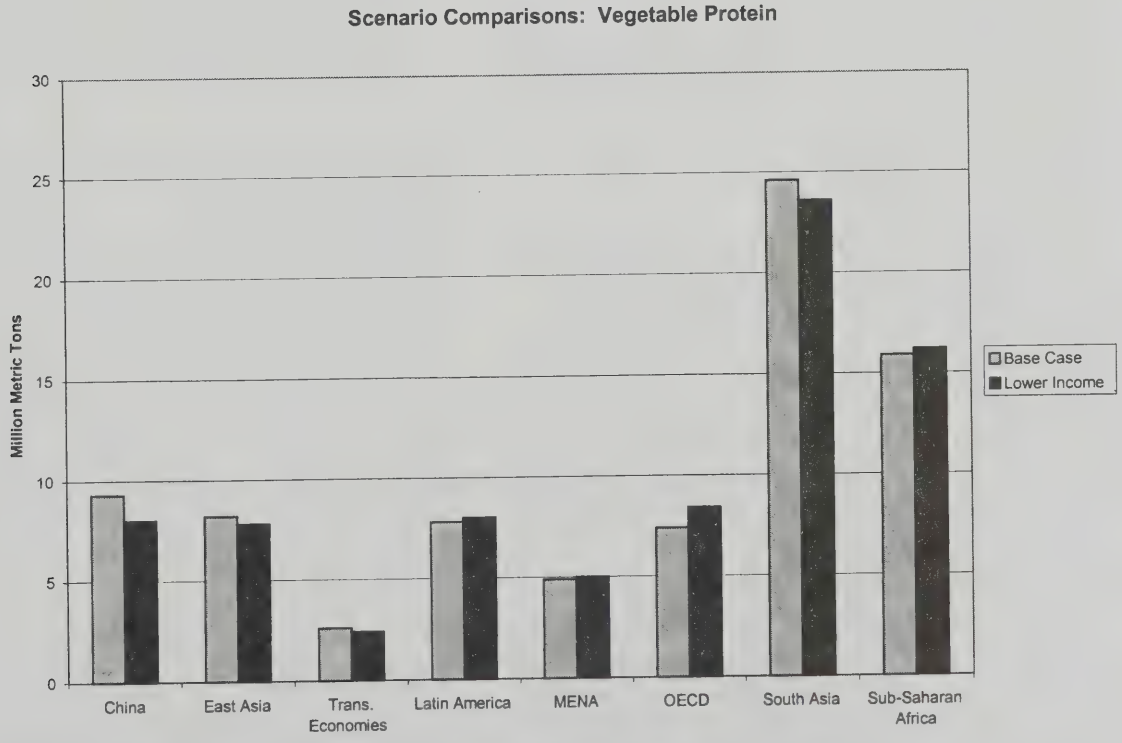


**Figure 6. Scenario comparisons for vegetable protein appetite in the year 2025.**

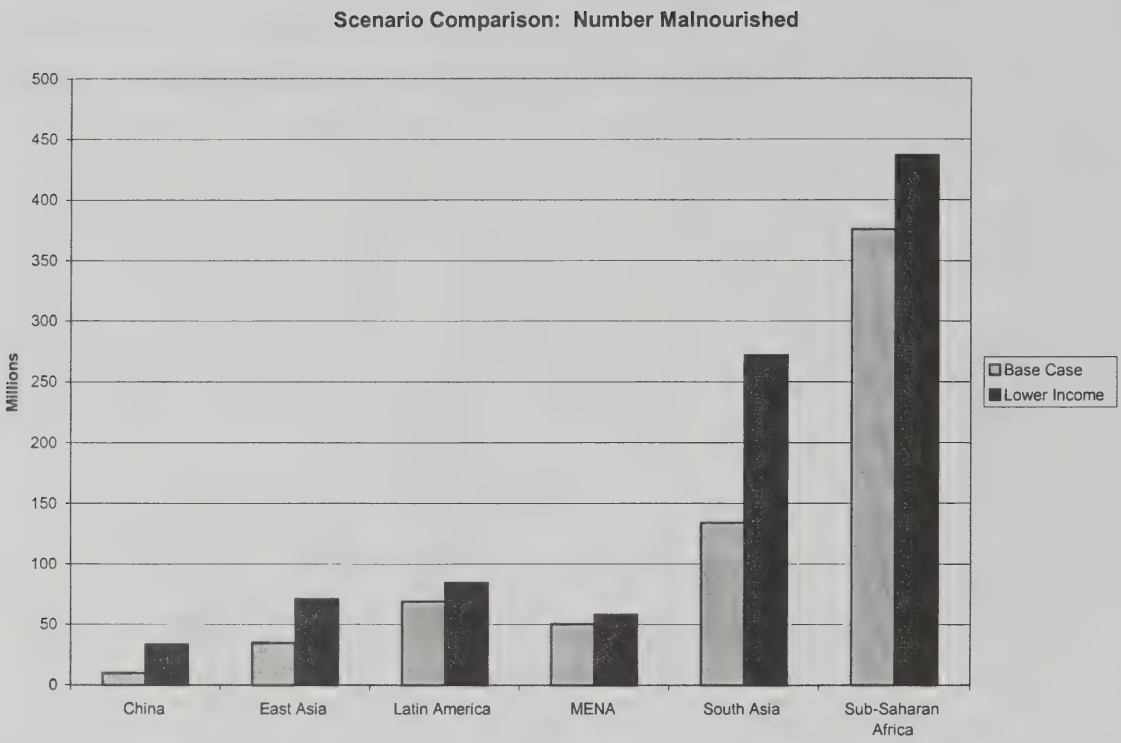


**Figure 7. Scenario comparisons for number malnourished in the year 2025.**

however, even the economic aspects of globalization involve more than trade. The rise of multinational corporations, low-cost communication technologies, and new managerial techniques now allow for the production and assembly of products in several countries before the country in which the product is finally assembled or sold. Throughout the economy the growth of foreign direct investment by multinational corporations has been a topic of intense debate and discussion.

Relative to agriculture and food, international economics focused on trade of commodity products. For U.S. agriculture, the growth of trade in processed food products has exceeded the growth of commodity trade for the past 20 yr. Indeed, the export value of processed foods from the United States exceeded that of agricultural commodities in the early 1990s. Foreign direct investment by multinational agribusiness and food firms has paralleled the massive growth by foreign direct investment by firms throughout the economy.

Projecting to the future, globalization, if it occurs, will emphasize foreign direct investment, technology transfer of knowledge, and an increasing role for intangible assets based upon intellectual property rights. This emphasis will be true for food and agriculture as for other components of the economy. One factor that needs to be considered is that the rapid exchange of basic and applied information about agriculture has been the norm for the past few decades. This exchange has been much more fluid in agriculture than it has been for the rest of the economy. Therefore the differential effect in agriculture may be less pronounced than otherwise might be expected.

Agriculture has benefited for decades from research and the explicit knowledge produced by research. However, agriculture has tended not to extensively use more tacitly based knowledge systems that coordinate supply chains. With the intense interest that has developed regarding food system traceback and accountability, it is likely that such firm specific knowledge will become more valuable to the effective production and manufacturing of food products. These systems are likely to be integrated within vertically linked food supply chains. The notion that global food supply chains will evolve to play a prominent role in tomorrow's agriculture is predicated on the assumption that globalization will be a major force in the future.

## SUMMARY

Globalization is a concept that didn't commonly exist before the 1990s, emerged to become synonymous with

rapid worldwide economic growth, and was the reviled rallying cry for violent protests in Seattle and Milan. It is widely acknowledged, even by opponents, that globalization is correlated with economic growth. However, its effects extend beyond market transactions to include effects on social and cultural norms. Similarly globalization is the product of complex intertwined forces that include technological advances, new financial tools and capabilities, communications, and capitalism.

Relative to agriculture and food, the linkage between globalization and economic growth is critical. Economic growth in developing nations is important to the future well being of the world's people. And as income increases in developing nations, significant financial resources are devoted to additional food purchases. The magnitude of these additional food purchases will have a major role in determining the profitability of food production in the future.

To most of us, globalization achieved its zenith relatively rapidly over the past decade or so. And because of its profound impact in the 1990s, there is a tendency to assume it will continue unabated. That assumption is not necessarily a good one as illustrated in the following paragraph:

> "What an extraordinary episode in the economic progress of man. The resident of London could order by telephone, sipping his morning tea in bed, the various products of the whole earth, in such quantity as he might see fit, and reasonably expect early delivery at his doorstep; He could at the same moment and by the same means adventure his wealth in the natural resources and new enterprises of any quarter of the world. What an extraordinary episode in the economic progress of man that came to an end in August, 1914" (Micklethwait and Wooldridge 2000).

Many of us believe that globalization is liberating to the human spirit as well as conducive to economic growth. For those of us concerned with agricultural profitability, future economic growth is critical. Whether our concern is economic growth or more general human well being, it is not just enough to assume that globalization will increase or even be maintained.

## REFERENCES


Bread for the World (BFW). 1998. *The Changing Politics of Hunger: Ninth Annual Report on the State of World Hunger*, Maryland: Bread For the World Institute.

Coplin, W.D. and M.K. O'Leary. 1994. *The Handbook of Country and Political Risk Analysis*, Political Risk Services, 378, New York.

*The Economist*. The Case for Globalization: 1-30. September 29-October 5 2001.

Fisher, D.K. 2000. *Assessing How Information Affects Cognitive Maps of Strategic Issues*, Unpublished Ph.D. dissertation, University of Illinois, Champaign-Urbana.

Ferris, J.N. 1998. *Agricultural Prices and Commodity Market Analysis*, McGraw Hill Book Company, Boston.

Friedman, T.L. 1999. *The Lexus and the Olive Tree*. Ferris, Straus, and Giroux, New York.

Micklethwait, J. and A. Wooldridge. 2000. *A Future Perfect*. Crown Business, New York.

# Food and Agricultural Policy: Bringing New Stakeholders and Issues into the Debate

**MARY KIRTLEY WATERS**

In mid-September, the U.S. Department of Agriculture released the report, "Food and Agricultural Policy: Taking Stock for the New Century," which outlines the Bush Administration's farm policy principles. This new publication details the enormous changes that have taken place in agriculture that continue to accelerate across the American food and farm sector.

Since the beginning of the year, the occurrence of several major events has reinforced the urgency of a comprehensive review of today's agriculture–all of the policies, programs, and other supporting infrastructure. It is critical that our policies, regulations, and supporting institutions keep pace with new technology, the shifting business environment, and our industry structure.

The food and agriculture system is driven by the same forces shaping the U.S. economy–globalization of markets and cultures; advances in information and biological, and other technologies; and fundamental changes in the workforce and family structures. Given the enormity and pace of change, the report recommends that policymakers take stock to examine past policies and programs and, where necessary, define anew goals and principles that can best guide the future growth and development of the farm, food, and agriculture industry in the new century.

Designed to guide policy development as lawmakers work on a new farm bill, the administration's principles address trade, a farm safety net, agricultural infrastructure, conservation and environment, rural communities, nutrition and food assistance, and program delivery, as summarized below:

- Farm policy and programs must be tailored to reflect wide differences among farms with respect to production costs, marketing approaches, management capabilities, and household goals.
- Farm policy, including providing a safety net, must promote more sustainable prosperity for farmers through market orientation without engendering long-term dependence on government support. This market orientation does not rule out helping farmers and ranchers when unexpected events beyond their control occur and cause output or income to plummet.
- Trade policy must focus on gaining access to foreign markets through tariff reduction and the elimination of trade-distorting subsidies and be supported by domestic policy that meets our existing international obligations and provides ample latitude to pursue ambitious goals in trade negotiations.
- Domestic farm policy must not inadvertently reduce competitiveness at the same time that trade policy seeks expanded export market opportunities for farmers.
- The infrastructure that supports market growth and efficiency, which includes everything from border inspection services to research endeavors, must be renewed and reoriented to fit today's realities, with input and cooperation from every link in the food chain.
- Conservation policy must pursue a portfolio of instruments, including stewardship incentives on working farmland or retirement of environmentally sensitive land to respond to Americans' growing expectations about agriculture's role in promoting and protecting environmental quality.
- A strong commitment to ensuring the access of all Americans to a healthy and nutritious food supply must continue, with particular attention to improvements in the delivery of food assistance to low-income families.

- Recognition of emerging diet quality issues is of paramount importance, as the nation's concern shifts from under-consumption and under-nutrition to that of the proper variety and quantities of foods and nutrients that promote health and well-being.
- Rural America is diverse and tailored policies must create conditions that attract private investment, encourage the education of the rural labor force, and promote alternative uses of the natural resource base, including through development of renewable energy sources and carbon sequestration to reduce greenhouse gas emissions.
- Systems must be integrated to assure coordinated and collaborative delivery of food and farm programs and to citizen access to public services.

The report suggests that fundamental, far-reaching changes in policy, programs, procedures, and institutions may be required to best prepare the nation's farmers, ranchers, and food industry as a whole for the new world marketplace.

# Government Payments and the Farm Sector

**NEIL CONKLIN**

# Soybean Cyst Nematode and Soybean Sudden Death Syndrome in Illinois

JASON P. BOND AND JOHN S. RUSSIN

## SOYBEAN CYST NEMATODE

Soybean cyst nematode (SCN), *Heterodera glycines*, is the most economically important pathogen of soybean. Each year, SCN robs Illinois soybean producers of more than $160 million in yield. Soybean cyst nematode was first detected in Illinois in 1957. Since then, SCN has spread to nearly all soybean-producing counties. In 2000, the Illinois Soybean Cyst Coalition reported that more than 40% of samples submitted for soil testing contained cyst counts that were over threshold levels.

In high-yielding environments, aboveground symptoms of SCN injury are usually not apparent. In the absence of symptoms, yield of susceptible soybean varieties can be reduced by 15–30%. Under heavy SCN infestation concomitant with biotic or abiotic stresses, plants can be stunted and chlorotic.

Host resistance has reduced the impact of SCN. Currently, there are more than 400 SCN-resistant varieties that are available to Illinois producers. After infestation has been detected the rotation of nonhosts and soybean resistance sources should be initiated. Rotation, when practiced, is limited primarily to single-year rotations with corn. Under this management, populations of SCN quickly adapt to the selection pressure imposed by resistant varieties and these varieties become less effective. Therefore, the heavy reliance on genetic control has the potential to predispose soybean production systems to a myriad of other constraints.

## SOYBEAN SUDDEN DEATH SYNDROME

Soybean sudden death syndrome (SDS) is the second most important soybean disease in Illinois. This disease was first described in Arkansas in 1970 and is caused by the soilborne fungus *Fusarium solani* f. sp. *glycines* (FSG). In 1985, the disease was identified in Illinois. Initially, sudden death syndrome was sporadic and would occasionally caused severe yield loss. Over the past 10 yr, SDS has become a major disease that causes significant yield loss.

Root infection by the fungus occurs 2 to 3 wk after the seedling emerges and is followed by a root-rot phase. When the plant reaches the flowering stage a leaf scorch phase is expressed, usually when the plant is growing under cool or moist conditions. Expression of foliar symptoms is a result of toxins that are produced by the fungus and that are translocated in the plant. Leaf symptoms begin as small, irregular chlorotic spots that become necrotic. These spots quickly enlarge and coalesce into larger, necrotic bands. Under severe foliar expression, pods can be aborted and leaves drop prematurely, leaving only the petioles attached. The amount of yield loss depends on how early foliar symptoms are expressed in relation to the growth stage of the plant.

An annual survey carried out by researchers from Southern Illinois University and University of Illinois has been conducted since 1998 (Figure 1). In this "windshield survey," a representative sample of fields is selected in each county and the fields with SDS foliar symptoms are recorded. In 1998, the incidence of SDS was great throughout Illinois. Counties with the greatest number of fields with foliar symptoms were in the central and northern portion of the state. In 1999, most of southern Illinois was under drought conditions throughout the growing season. Drought was not a concern for central and northern Illinois and the incidence of SDS was much higher. In 2000, SDS reached epidemic levels and losses exceeded $300 million in Illinois. The incidence and severity were the highest in the 4-yr survey. Throughout the state, some fields experienced yield losses exceeding

50%. In 2001, the incidence was more sporadic, however, many fields experienced significant yield loss. With the exception of some northern tier counties, SDS has been identified in all soybean-producing counties of Illinois.

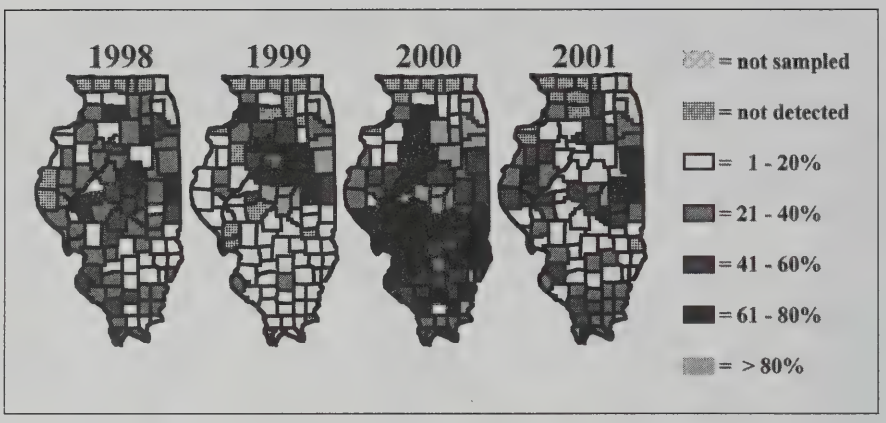


**Figure 1. Distribution of soybean sudden death syndrome as reported by Glen Hartman, Oval Myers, Jr., Wayne Pedersen, John Russin, and Jason Bond. Color-coding corresponds to the percentage of fields sampled that contained foliar symptoms of SDS.**

Host resistance is the primary means to manage this disease. Currently, only partial resistance is available in a low number of varieties. Each year, more than 800 varieties are evaluated for field resistance at locations throughout the state. In addition, breeding programs at Southern Illinois University-Carbondale and University of Illinois at Urbana-Champaign are continuing to look for new sources of resistance and are developing high-yielding varieties with resistance to this disease.

Sudden death syndrome is favored by cool, damp conditions and is most severe in high-yielding environments. For many years, producers observed that the disease was more severe in areas that would tend to have high levels of soil compaction such as turn rows and field entry points. Research at Southern Illinois University-Carbondale and University of Illinois at Urbana-Champaign has investigated the possibility of using various tillage practices as management strategies. At two locations in southern Illinois research sites were selected to evaluate the effects of deep tillage (14-16 inches), conventional tillage, and no-till on SDS. By using deep tillage to decrease soil compaction, SDS foliar symptoms were reduced by as much as 50% (Figure 2). However, the treatments did not have a discernable effect on the amount of FSG in the roots. At one of the two sites, SCN reproduction doubled in the tillage plots compared with the no-till plots (Figure 3). This trend continued through the corn rotation and was still significant when the 2001 soybean crop was planted. Deep tillage can be a viable practice to help minimize the severity of SDS if soil compaction is an issue, and erosion concerns are addressed. However, this practice will not eliminate SDS,

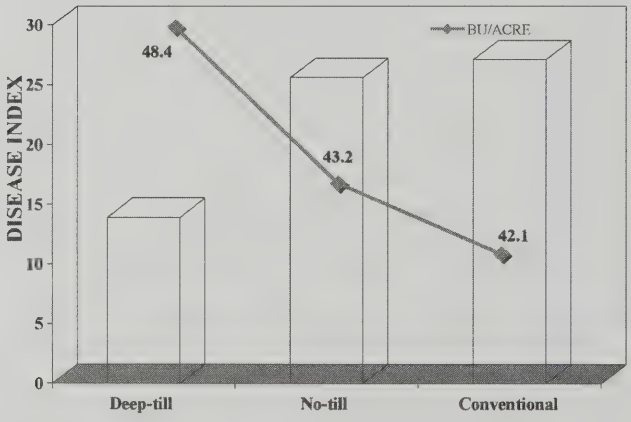


**Figure 2. Sudden death syndrome disease index (incidence x severity) as influenced by tillage in Carmi, IL. Disease index and yield were significantly different in the deep tillage plots as compared to no-till or conventional plots.**

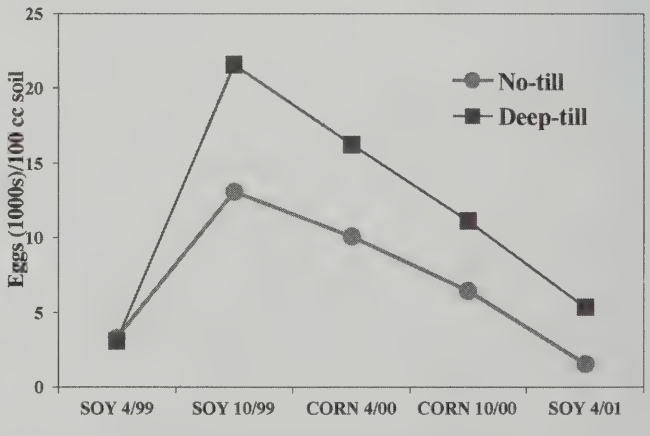


**Figure 3. Soybean cyst nematode reproduction as influenced by tillage in DeSoto, IL. Reproduction was significantly higher in the deep-tillage plots at all sampling dates after the initial sampling date.**

and in many years producers will still suffer yield loss. Host resistance and variety selection continue to be the preferred management strategy.

Recently, there has been a renewed interest in using crop rotations to help manage SCN and SDS. Species diversity in soybean rotation systems has decreased over the past 10 yr. The increased incidence and severity of many diseases may have been aided by a single crop in rotation with soybean. Projects at Southern Illinois University-Carbondale and University of Illinois at Urbana-Champaign are currently exploring the benefits of integrating wheat, rye, canola, and other crops into rotation systems to reduce soilborne pathogens. Other research projects are being initiated to gain a greater understanding of the interactions between SCN and FSG, including studies on the biology and pathogenicity of the organisms and the genetics of the host parasite interaction.

Many of the fields in Illinois are infested with SCN and FSG. Research has shown that the presence of SCN can increase the severity of SDS. However, SCN is not needed for plants to be infected with FSG or be heavily damaged by the fungus. However, managing SCN is imperative and may provide additional benefits by reducing the severity of SDS. Producers need to sample for SCN and periodically sample throughout the rotation of nonhosts and resistance sources. Management of both pathogens continues to include the use of resistant varieties, rotation of these varieties with nonhosts, and diligent soil sampling.

## ACKNOWLEDGEMENTS

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## SUGGESTED REFERENCES

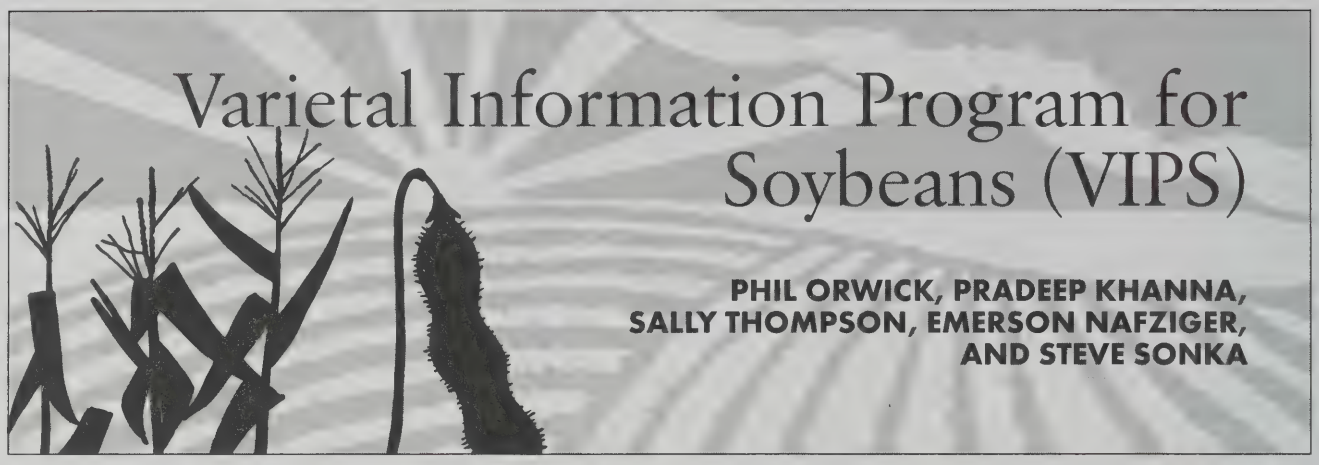
Hartman G.L, J.B. Sinclair, and J.R. Rupe. (Eds.). 1999. Compendium of Soybean Diseases, 4th ed. American Phytopathological Society, St. Paul, MN.

Niblack, T.L. (ed.). 1999. Soybean Cyst Nematode Management Guide. North Central Soybean Research Program Publication. University of Missouri Printing Service, St. Paul, MN.

Riggs, R.D., and J.A. Wrather. (eds.). 1992. Biology and Management of the Soybean Cyst Nematode. American Phytopathological Society, St. Paul, MN.

Roy, K.W., J.C. Rupe, D.E. Hershman, and T.S. Abney. 1997. Sudden death syndrome of soybean. *Plant Disease* 81: 1100-1112.

Schmidt, M.E., W.L. Pederson, and J.S. Russin. 2001. Soybean sudden death syndrome variety test results (online). Southern Illinois University. Available at http://www.siu.edubsoybean/sdscomm2001.html



# Varietal Information Program for Soybeans (VIPS)

**PHIL ORWICK, PRADEEP KHANNA, SALLY THOMPSON, EMERSON NAFZIGER, AND STEVE SONKA**

The Varietal Information Program for Soybeans (VIPS[1], http://web.aces.uiuc.edu/VIPS) was designed as a tool to help producers make the transition to soybean marketing based on seed quality attributes. Although all participants in the soybean value chain–producers, processors, scientists, strategic planners, marketing innovators, and agricultural consultants–have used VIPS, the greatest use has been among producers. Their main interest has been in getting information to help in making near-term planting decisions. They have indicated a strong interest in obtaining information on yield, protein, and oil by variety that is integrated with information on disease susceptibility. Producers also have indicated the need to simplify the process of obtaining variety information they need to make short-term planting decisions.

VIPS has been developed over the past 3 yr into the one-stop source of electronic information to assist Illinois soybean producers in their soybean variety decisions. VIPS uses data compiled from the University of Illinois Variety Trials conducted at 12 locations throughout the state, along with information on resistance or susceptibility to major soybean diseases, to provide soybean growers with a query structure to assist in making an informed decision on what variety will best suit their needs.

## VIPSPRODUCTION

The query structure of VIPS has been divided into two parts: VIPSproduction and VIPScomposition. In VIPSproduction, the new query structure makes it easy for producers to extract valuable information for their planting decisions. Producers can search and rank data in several ways. Information can be obtained by location, company, maturity group, and type of soybean (conventional or Roundup Ready). Users also can get information on a company's participation in all VIPS trials as well as display and compare a company's results in each trial. Furthermore, users can select individual varieties and view all results for the selected variety at once. They also can obtain specific information on the environmental and agronomic factors for each trial location and download results of their queries in a spreadsheet for further analysis. No username or password is required to use VIPSproduction.

For the varieties at the 12 Illinois locations in 2001, data on yield, percentage of oil content, and percentage of protein content are available. In addition, disease resistance and susceptibility data for each of the varieties in the trials will be rated by University of Illinois plant pathologists and included in the query structure. Major diseases that are included in the ratings are soybean cyst nematode, sudden death syndrome, white mold, and Rhizoctonia root rot.

## VIPSCOMPOSITION

The second component, VIPScomposition, is designed for users interested in in-depth analysis of soybean composition. VIPScomposition provides information on 31 end-use attributes of soybean composition for many of the varieties included in the 2001 variety trials. The VIPScomposition database includes values for attributes such as fatty acids, amino acids, and isoflavones. Information is also available from 1998, 1999, and 2000 soybean trials by the University of Illinois, Iowa State University, Soy Capital bank, and Mycogen (now a part of Dow Agrosciences).

[1] VIPS was developed by researchers at the University of Illinois and Iowa State University and was initially funded by the Soybean Research and Development Council. The Illinois Soybean Program Operating Board is providing continuing funding.

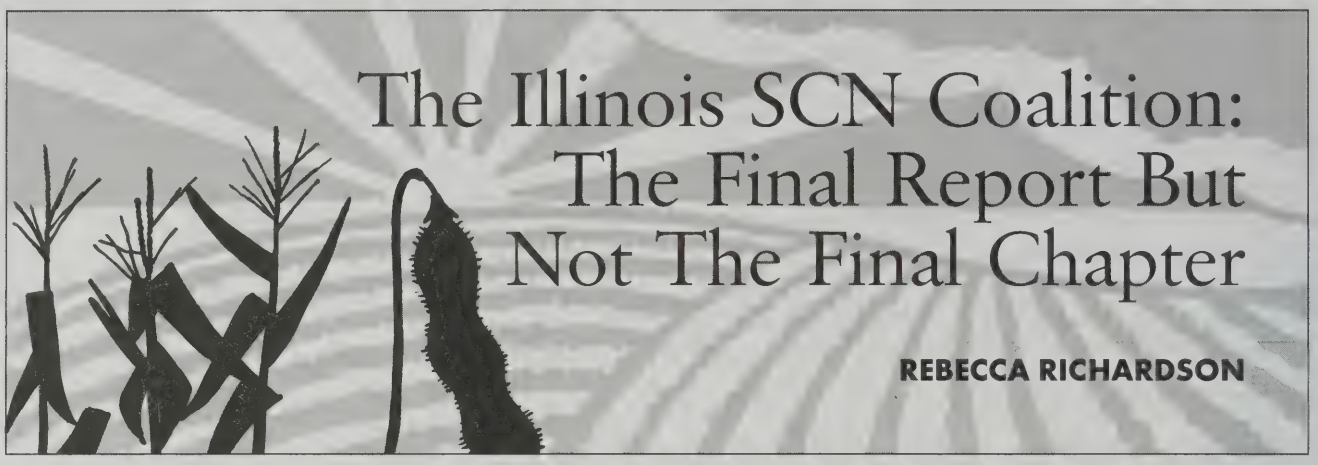
To use VIPScomposition, click on the VIPScomposition link from the VIPS home page. Use of VIPScomposition entails a simple, one-time, registration process to obtain a username and password. To register, click on the *Access Request Form* near the bottom of the VIPScomposition page. Immediately after users complete and submit the registration form, they receive a confirmation by e-mail with their chosen username and password. Users may then access the VIPScomposition database immediately. A brief tour of VIPScomposition is available by clicking on *Introduction to VIPS-Composition Capabilities.*

## LINKS

VIPS provides links to information on control of weeds, insects, and pathogens from universities in Illinois as well as surrounding states. Also included are links to up-to-date weather information and a direct link to the Illinois Agricultural Pest Management Handbook on-line with an index to soybean-related topics. A new Expert-on-Call section has recently been added to VIPS. It provides links to the frequently asked questions of StratSoy (http://stratsoy.ag.uiuc.edu), where experts on management of field crop diseases, weeds, insects, and production are available to answer questions.

## SUMMARY

The enhancements and modifications to VIPS over the past 3 yr make it a powerful information tool for producers to help them in making their planting decisions. As a one-stop source for production-related information, VIPS saves producers time spent searching for information on the Internet and elsewhere. The producer-friendly user interface makes VIPS valuable for producers who are not Internet savvy. VIPS will continue to help producers make the transition to soybean marketing based on seed quality attributes as well as continue to be the primary source of reliable, unbiased, and accessible information on seed yield, oil content, protein content, and disease information for soybean varieties tested in the University of Illinois Soybean Variety testing program.



# The Illinois SCN Coalition: The Final Report But Not The Final Chapter

**REBECCA RICHARDSON**

For many years, Illinois soybean farmers have known that *Heterodera glycines*, or soybean cyst nematode (SCN), is the number one disease threat to soybeans in the north central United States. Each year, SCN robs U.S. soybean producers of more than $1 billion in yield losses, making the approximate loss for Illinois $200 million annually. It is estimated that SCN is found in 30 states, and it is likely that SCN will soon occur in all soybean production areas in the United States. In Illinois, SCN has been identified in all but three extreme northern counties.

In the mid-1990s, the Illinois Soybean Checkoff Board (ISCB) and the Illinois Soybean Association (ISA) recognized SCN as a battle that needed to be fought. Since 1997, the ISCB and ISA have supported the efforts of the Illinois SCN Coalition, as have several other organizations. The Coalition brought together the Illinois Soil Testing Association, Illinois Seed Trade Association, Illinois Crop Improvement Association, Inc., University of Illinois, University of Illinois Extension, ISCB, and ISA to encourage Illinois soybean farmers to test for and battle SCN in their fields. In Illinois, 44 soil testing laboratories and 21 seed companies became partners of the Illinois SCN Coalition.

ISCB provided the funding for the SCN project and ISA furnished the communication vehicles that reached members and other soybean producers in the state. The soil testing association helped to oversee cooperating laboratories and the seed trade association worked with its members to provide SCN training and materials that were passed on to their customers. University of Illinois Extension worked with the coalition in Illinois to train technicians from the laboratories and field agents from the seed and chemical companies about the technical aspects of SCN testing and management.

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Edited from the Illinois Soybean Checkoff Publication "The SCN Final Report", 2001.

## SCN PROGRAM GOALS

The Illinois SCN Coalition set out four basic objectives in 1997:

1. increase producer awareness of SCN, and influence producer decisions and behaviors that will minimize the yield loss due to SCN;
2. develop a state coalition of partners and cooperators who will serve as the delivery network for the program;
3. increase producer and industry knowledge and awareness of the soybean checkoff program and its plan to work cooperatively with other statewide organizations and regional partnerships to maximize farmer investment; and
4. establish and develop a statewide SCN database that will measure infestation levels over time.

## PROGRAM EVALUATION

Once the Illinois SCN Coalition was implemented, the ISCB and ISA needed means by which to assess the program and its outcomes. To evaluate the effectiveness of the program, ISCB and ISA measured results by data analysis, a survey of partners and cooperators, and a farmer attitude survey over the 3-yr period of the program.

## THE SCN PUBLIC DATABASE

Through the Illinois SCN Coalition's database program–the most comprehensive registry of SCN testing information ever compiled–more than 40,000 soil samples have

been collected and analyzed since fall 1998. Data indicated that in 97 Illinois counties, average infestation ranged from 1 to 41 cysts per 100-cc soil sample, and 43% of all the samples showed infestation above the state's threshold. In Illinois, the action threshold, or the point of economic impact, for SCN is three viable cysts or 150 eggs or larva per 100 cc of soil. This threshold is the level at which the use of resistant varieties and crop rotations should be considered.

The SCN public database was a vital part of the Illinois SCN Coalition. The database information includes county-by-county cropping history, soil types, infestation levels, and varieties planted, along with SCN levels found in the samples. Information on cyst levels by county can be accessed at www.ilscncoalition.org. The primary goal of the database program was to motivate Illinois soybean producers to test their soil for SCN. If it was determined that the level of infestation was above three viable cysts or 150 eggs/larvae in 100 cc of soil (the action threshold in Illinois, at which point farmers need to consider resistant varieties and crop rotation), the producer was advised to plan resistant rather than susceptible soybean varieties and would be informed of other management practices, such as crop rotation and use of nonhost crops, that could provide better yield potential.

Although there was little data to determine the percentage of soybean acres that had been sampled before the establishment of the public database, testing during the course of the 3-yr program increased in each region of the state each year. By January 2001, the northwestern and southern areas of Illinois had sampling rates just below 5% of total soybean acres in those areas. The central, northeastern, and western areas showed sampling rates between 5 and 10%. The eastern region of the state had a sampling rate above 10%. Statewide, the sampling rate averaged 6.93%.

## PARTNERS

Partnerships with soil testing laboratories and seed companies helped to broaden Illinois SCN Coalition information and education programs. This approach benefited Illinois soybean producers by providing a wide range of outlets for SCN testing and management information. The partnership formula also helped to add cost-efficient communication channels for SCN information and materials. For the partner laboratories and seed companies, Illinois SCN Coalition efforts helped them help their customers achieve higher profitability. Simply put, all partners used a simple message to convey to farmers the action necessary to confront SCN: "Take the Test. Beat the Pest."

A variety of survey instruments were used to provide feedback from state partners and cooperators as to how effective they thought the Illinois SCN Coalition was in terms of affecting soybean farmer profitability. Throughout the 3-yr effort, seed company cooperators indicated they were distributing Illinois SCN Coalition materials to their customers at field days, customer visits and their own direct mail efforts. In a 2001 survey, seed company representatives said their SCN-resistant seed sales increased by an average of 13%; some respondents indicated that SCN-resistant variety sales increased by nearly 30% over the course of the program.

## COMMUNICATIONS

Since the beginning of 1999, the Illinois SCN Coalition has offered SCN information and data on its Web site at www.ilscncoalition.org. The site provided a county-by-county map with SCN population average levels and the number of samples farmers in each county have submitted through the public database program. Since early 1999 through May 2001, more than 24,000 people from across the United States and several foreign countries visited the site. Illinois farmers also were reached with SCN information at a variety of farm shows, field days, and grower meetings and direct mailing pieces.

## FARMER ATTITUDE SURVEYS

An attitude survey was used to study trends over the program's 3-yr period to measure shifts in soybean farmers' awareness of SCN and the SCN Coalition efforts. Illinois soybean farmers' positive responses to the importance of identifying SCN increased from 66 to 80% during the program. The number of farmers using scouting practices increased during the same time period from 48 to 58%. One of the greatest challenges in the battle against SCN is that damage can be done even if there are no aboveground symptoms. Illinois soybean farmers' belief of the accuracy of the statement "Even though SCN symptoms are patchy within fields, SCN can be present throughout the entire field" increased from 59 to 75% during the program.

## SAMPLING AND EDUCATION THROUGH INDUSTRY INFLUENCERS

Three additional projects directed by the Illinois SCN Coalition yielded soil samples from a variety of locations in Illinois. The results continue to provide farmers, farm managers, seed companies, and fertilizer and chemical dealers with information about SCN levels, soil type, growing conditions, and agronomic practices.

### Higher Profits – Greater Losses for Illinois Seed Growers

The first of these projects was focused at soybean seed growers in Illinois. Much of the recent educational information efforts to demonstrate SCN's yield and economic impact have focused on soybean farmers, yet hundreds of thousand of tillable acres in Illinois are devoted to soybean seed production. The focus of a survey project conducted by the Illinois Crop Improvement Association, Inc., was to look at the occurrence and levels of SCN in seed production fields across the state. In the more than 11,400 soil samples collected from 3,500 seed production fields across Illinois, a 3-yr average of 44.5% showed cyst counts above economic threshold. Additionally, some of these soil samples were shared with Greg Noel, University of Illinois, for race testing and identification. Aside from statewide SCN egg and cyst information, the survey also provided information on more than 230 seed production fields planted with soybean in 1998 and then again in 2000. The results may provide additional information about crop rotation strategies as a management tool for SCN.

## TWELVE-COUNTY STUDY LINKS SCN LEVELS AND PH LEVELS

A second study, conducted in 12 counties in east central Illinois, used georeferencing to provide mapping that illustrated yield loss due to SCN. These counties (Kankakee, Iroquois, Vermilion, Ford, Champaign, Grundy, Livingston, McLean, DeWitt, Piatt, Woodford, and LaSalle) represent approximately 5 million acres of production cropland. According to the 1997 Ag Census, they produced nearly 102 million bushels of soybean, totaling nearly $510 million in revenue. With an estimated 5% yield loss to SCN, the potential revenue loss totals more than $25 million to farmers in the 12-county area alone. GMS Laboratories in Cropsey, IL, conducted the survey. Over the 3-yr project, nearly 1,000 sites, each representing 40-acre areas, were sampled and information evaluated including BPS location, crop history, soil type and fertility, and SCN levels.

Each of the fields in the survey was global positioning system (GPS) mapped. Each participating farmer received a georeferenced map, including SCN, pH, phosphorus, potassium, organic matter, and soil type information. The farmers who had elevated SCN populations received advice about planting rotations, host and nonhost crops, as well as the use of susceptible and resistant soybean varieties.

During the 3-yr survey, certain locations isolated a common thread to the high-pressure zones. Through soil fertility testing, it was found that areas showing a higher soil pH had higher SCN populations. Additional testing via the GPS coordinates established in this project, combined with updated field and cropping histories, could give Illinois farmers better insight into the environment, and ultimately the controls, by which SCN thrives or moderates.

## STATEWIDE FARM MANAGER OUTREACH

In Illinois, professional farm managers play a critical role in the oversight and management of family farms for absentee owners. Statewide there are more than 400 farm managers who oversee 3.7 million acres–approximately 15% of Illinois' total cropland. As part of the Illinois SCN Coalition's efforts to inform farmers about the devastating effect of soybean cyst nematode, a 3-yr effort surveyed more than 31,000 acres statewide overseen by selected farm managers.

Field information about producer inputs and management practices was evaluated along with SCN levels. Sixty-six farm managers in various locations throughout Illinois had soil samples analyzed by SI Nematode Lab, Inc., Raleigh, IL, and fertility samples analyzed by Key Ag, Macomb, IL. A total of 3,177 soil samples was processed and results were correlated with GPS references and shared with farm managers. The participating farm managers and tenants received GPS grid maps on 10-acre locations. These maps included a field perimeter map, soil sample grid map, and SCN analysis map. Fertility data were provided to the farm managers and tenants on a spreadsheet with sample points correlating to a soil samples grid map. Crop consultants also met with each farm manager and supplied them with SCN education materials that were either created or reviewed by University of Illinois Extension.

During the 3 yr of the project, the researchers surveyed acreage in nearly 40 Illinois counties. In those counties, 30.2% of the samples showed SCN levels above three cysts or 150 eggs/100-cc soil sample, the economic threshold in Illinois. Every county tested had samples above threshold.

## THE FINAL REPORT – NOT THE FINAL CHAPTER

The Illinois SCN Coalition dramatically raised awareness of the widespread infestation of SCN in our state. SCN continues to reduce soybean yields across the state. As widespread sampling during the SCN Coalition the past 3 yr has shown, most of the soybean farmers in Illinois have an SCN problem, but the problem may not be exactly what they think it is. They know, for example, that when SCN numbers are high, plants are stunted, yellow, and yield poorly. They know that planting SCN-resistant varieties helps them recover yields and may reduce SCN levels. But how many farmers with SCN-infested fields know that SCN can reduce yields 15 to 30% without causing any stunting or yellowing? How many are aware that a large percentage of SCN populations in Illinois are able to reduce yields of resistant varieties—not because the varieties lack resistance but because the nematode has adapted to them? How many farmers know how SCN is affecting their ability to manage other problems in soybean fields, such as weeds, insects, and disease-causing microbes?

Continued efforts to encourage soybean farmers to test their soil and to keep records on their infested fields will pay big dividends in the future as we understand more about how SCN interacts with the entire complex of biological, chemical, and physical characteristics that are unique to each farm.

## LOOKING AHEAD

A significant outcome of the Illinois SCN Coalition has been the formation of a statewide research and outreach team. This multidisciplinary, multi-institutional team is a diverse and talented group of extension and research personnel from the University of Illinois and Southern Illinois University at Carbondale. All of the team members have been drawn together by a common interest in understanding and managing SCN, and the Illinois SCN Coalition gave impetus to the group's goals and work.

Significant investigative efforts by Illinois SCN Coalition partners are being finalized. University of Illinois Extension has been and will continue to be involved in the analysis and database management brought forth by these studies. Results will be made available to Illinois soybean farmers on the Web as the Illinois SCN Coalition Web site transitions to maintenance by the University of Illinois.

Additionally, producers can look forward to expanded data about SCN on the Varietal Information Program for Soybeans (VIPS) Web site so they can make informed SCN management variety selections. The information will be available at http://web.aces.uiuc.edu/VIPS or www.stratsoy.uiuc.edu.

One of the most important things the Illinois SCN Coalition did was to begin the process of standardizing the methods for processing soil samples to detect and count SCN. Because all SCN management recommendations are based on nematode numbers, this standardization is very important. When one laboratory talks to another, or when one farmer talks to another about SCN test results, it is important that they are talking about the same units.

A big change in diagnosing SCN problems and making recommendations will be in the way we treat differences among SCN populations. In the past, we always talked about SCN "races" and how they differed in their ability to attack resistant varieties. Unfortunately, the situation in the field is a lot more complicated. A new way of characterizing SCN populations, called the HG Type test (HG stands for the Latin name of the nematode, *H. glycines*), is currently being tested. This new system may provide information to make much better recommendations for SCN management, once coupled with the variety screening program.

Through education and research programs, much has been accomplished, but farmers need to remain vigilant in their efforts to manage SCN. Soil testing on a scheduled basis is effective in determining whether there is an infestation problem, and the use of SCN-resistant varieties allows a farmer to grow soybean with strong yields while managing SCN numbers. However, it is just as important to know you do not have an SCN problem. Planting soybean with the same resistant markers year after year can lead to new variants of SCN. Farmers should continue to talk about SCN with fellow soybean farmers, seed and product representatives, crop consultants, and University of Illinois Extension personnel.

# Soybean Cyst Nematode: The Race Is Off

TERRY NIBLACK

Thanks to decades of hard work and cooperation between nematologists and soybean breeders, today we have soybean cyst nematode (SCN)-resistant cultivars with excellent agronomic characteristics. Many growers have been so pleased with the results they're getting from the use of resistant cultivars that they're tempted to use the same ones repeatedly. This practice can create bigger SCN problems over time, because resistant cultivars don't have complete resistance; that is, they allow a few nematodes to develop and reproduce. These successful worms are adapted to the resistant cultivar and can build up rapidly to yield-reducing levels. The yield reduction is often "hidden," that is, soybean fields suffering SCN-induced yield loss appear to be healthy (unless some other yield-limiting factor is stressing the plants).

The adaptation of SCN to resistant cultivars has been referred to in the past as "race shift." To farmers and seed producers used to dealing with the concept of race in *Phytophthora* or wheat stem rust, for example, this ideas seemed straightforward: put selection pressure on the SCN population and it will shift to a new race that isn't controlled by the resistance. Our understanding of SCN populations was at this level in 1970, when the first SCN race system was published (Golden et al., 1970). By the time the expanded race system was published in 1988 (Table 1; Riggs and Schmitt, 1988), our understanding of genetic diversity in SCN was much better, but no better scheme than the race system had been proposed (Niblack, 1992).

**Table 1. Races of the soybean cyst nematode, *H. glycines*, according to the race determination schemes of Golden et al. (1970) and Riggs and Schmitt (1988).**

| Race | Pickett | Peking | PI 88788 | PI 90763 |
|---|---|---|---|---|
| 1 | – | – | + | – |
| 2 | + | + | + | – |
| 3 | – | – | – | – |
| 4 | + | + | + | + |
| 5 | + | – | + | – |
| 6 | + | – | – | – |
| 7 | – | – | + | + |
| 8 | – | – | – | + |
| 9 | + | + | – | – |
| 10 | + | – | – | + |
| 11 | – | + | + | – |
| 12 | – | + | – | + |
| 13 | – | + | – | – |
| 14 | + | + | – | + |
| 15 | + | – | + | + |
| 16 | – | + | + | + |

Race determination is made on the basis of the pattern of + and – ratings for each race. A + rating is given if the number of females produced by an *H. glycines* population on each soybean differential is 10% of the number pr oduced on the standard susceptible cultivar Lee. If the number of females is <10%, a – rating is given.

## WHAT IS A RACE?

An SCN race designation is unlike those for races of other organisms, such as *Phytophthora*, for which the genotype of the pathogen is reflected by its virulence characteristics. For a population of SCN, only an average phenotype is reflected by its race designation.

To use Table 1, first take a soil sample from an SCN-infested site. From this sample, extract the eggs, which are used to infest containers of soil planted with seedlings of Lee (the standard susceptible) and each of the four

soybean differential lines: 'Pickett", 'Peking", PI 88788, and PI 90763. After 30 days at 27∞C and 16-h days, the plants are removed and the females washed from the roots. A female index (FI) can be calculated as follows: (number of females on differential) ∏ (number of females on Lee) ¥ 100. If the FI ≥ 10, the SCN population receives a plus (+) for that differential. If the FI < 10, the SCN population receives a minus (-). The pattern of + and - symbols on the four differentials determines the race designation for the population. Thus, the race designation is a population average, and it does not reflect a genotype because the differentials do not have mutually exclusive genes for resistance (as far as we know).

## WHY SHOULD WE CHANGE THE RACE SYSTEM?

The argument for keeping the race system is as follows: it has helped us develop resistant cultivars that have saved soybean farmers billions worth of soybean yields that would otherwise have been lost. The main argument for changing the system is equally good: it will not help us keep up with the changes in either soybean genetics or SCN genetic diversity that will be occurring in the future. We've reached a dead end with the usefulness of the race system; therefore, the choices are not to keep it or modify it, but to modify it or junk it entirely.

A group of nematologists, geneticists, and soybean breeders with years of experience working with SCN, met under the auspices of the United Soybean Board and decided to modify the race system by making the most conservative changes possible (Niblack et al., 2001). There are three major changes:

1. *The name will be changed to HG Type*. HG stands for *Heterodera glycines*, the Latin name for soybean cyst nematode. Type is free of the implications of race as a genotype designation.
2. *Pickett will be dropped from the list of soybean differentials*. Pickett was derived from a cross with Peking and has no demonstrably different genes for resistance to SCN.
3. *New differentials will be added, and referred to as indicator lines*. Four new sources of SCN resistance have been registered in the journal *Crop Science* since Peking, PI 88788, and PI 90763 were identified.

The HG Type test will be conducted essentially as described above for the race test. If the same method were used for finding a designation, we would now have 128 different Types to keep track of, which would be intolerable. HG Types will be named with numbers based on the indicator lines for which their FI ≥ 10 (Table 2). For example, an SCN population that produces FI ≥ 10 on PI 88788 would be an HG Type 3. Another population, with FI ≥ 10 on Peking, PI 88788, and Cloud, would be an HG Type 1.2.7. A population that produces no FI ≥ 10 would be an HG Type 0. In addition, anyone who designates an HG Type will be required to publish the FI as well. For example, simply designating a population as an HG Type 2 will be insufficient; the designation will have to be HG Type 2 with a FI of 65.

## HOW WILL THIS AFFECT YOU?

The HG Type system will probably not come into common use in the immediate future. Currently, the HG Type system is primarily a tool for soybean and nematode geneticists to describe SCN populations more precisely than we can with the race system. In the next couple of years, though, the HG Type system will replace the race system unless a system based on the identification of SCN genotypes is proposed.

For some time, specialists have been recommending that growers with SCN infestations rotate their resistant cultivars by switching sources of resistance or, for example, changing from a Race 3-resistant cultivar to a Races 3- and 14-resistant cultivar when they next grow soybean. This recommendation is still good and will be

**Table 2. HG Type classification scheme for genetically diverse populations of *H. glycines*.**

| | | FI[a] 10 on Indicator Host | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Indicator Line | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 1 | PI 548402 (Peking) | | + | | | | | | |
| 2 | PI 88788 | | | + | | | | | |
| 3 | PI 90763 | | | | + | | | | |
| 4 | PI 437654 | | | | | + | | | |
| 5 | PI 209332 | | | | | | + | | |
| 6 | PI 89772 | | | | | | | + | |
| 7 | PI 548316 (Cloud) | | | | | | | | + |

[a] Female index (FI) is determined as (the average number of females produced on each indicator line) ÷ (the average number produced on Lee 74) × 100.

unaffected by the HG Type system. Most growers do not know what races occur in their fields, and most will not need to know what HG Type they have. For those who do want to know, we are working on a modified or incomplete HG Type test based on the sources of resistance available to growers. Seed companies currently labeling their soybean cultivars according to race resistance will have to come up with a more informative label. It has been recommended that seed companies print the source of resistance on the label, but it may be some time before that or something similar happens.

## THE RACE ISN'T OFF ...

SCN will still be causing yield losses to farmers with infested fields, so the race to head off the damage isn't off. The rules are still the same. If a field hasn't been tested for SCN–test it. If a field has SCN–monitor it. If resistant cultivars are used–don't use the same one in the next rotation.

## REFERENCES


Golden, A.M., J.M. Epps, R.D. Riggs, L.A. Duclos, J.A. Fox, and R.L. Bernard. 1970. Terminology and identity of infraspecific forms of the soybean cyst nematode (*Heterodera glycines*). *Plant Disease Reporter* 54: 544–546.

Niblack, T.L. 1992. The race concept, in Biology and Management of the Soybean Cyst Nematode (R.D. Riggs and J.A. Wrather eds., pp 73–86. APS Press, St. Paul, MN.

Niblack, T.L., R.D. Riggs, P.R. Arelli, G.R. Noel, C.H. Opperman, J.H. Orf, D.P. Schmitt, J.G. Shannon, and G.L. Tylka. 2001. A revised classification scheme for genetically diverse populations of *Heterodera glycines*. *Journal of Nematology* (in press).

Riggs, R.D. and D.P. Schmitt. 1988. Complete characterization of the race scheme for *Heterodera glycines*. *Journal of Nematology* 20: 392–395.

# Assessing Corn Hybrid Sensitivity to Herbicides

**BRENT THARP**

Weed management is an integral component of successful crop production, and herbicides are the most common approach for achieving effective weed management. The lack of weed control can dramatically decrease yields, but sparse attention has been given to the effect of herbicides on grain yields for individual hybrids.

Hybrid sensitivity to herbicides is a misunderstood concept. Often, a herbicide is considered safe if it does not produce apparent visual injury symptoms. However, herbicides that cause dramatic injury symptoms, such as leaf burn, are generally considered unsafe. Golden Harvest Agronomy Up Front™ research has demonstrated that early-season injury is not always an indication of corn yield loss. In addition, the perception of a particular herbicide's crop safety is often based on visual symptoms on an array of hybrids and is rarely considered on an individual hybrid. Unfortunately, these generalizations do not promote sound herbicide management and can be a missed opportunity for growers to gain the maximum yield potential from their hybrids.

Corn hybrid sensitivity to herbicides is influenced by various factors, including weather, crop growth stage, application rate, soil type, and genetic variability. Understanding how these factors interact for individual hybrids is difficult and requires a concerted research effort. In 1983, Golden Harvest Seeds initiated an applied research program, called Agronomy Up Front, to evaluate the response of our seed products to various crop production inputs, including herbicides.

## TESTING METHODS

Golden Harvest Agronomy Research is conducted at eight locations across Illinois, Iowa, Michigan, Nebraska, and Wisconsin. Hybrids that are best adapted to a location's maturity zone are selected for testing, and herbicides are chosen based on their relative use in the Corn Belt. Herbicides are tested at the high end of the recommended label rate and applied at early and late recommended label timings. "Off-label" herbicide application timings or rates are not investigated in this research.

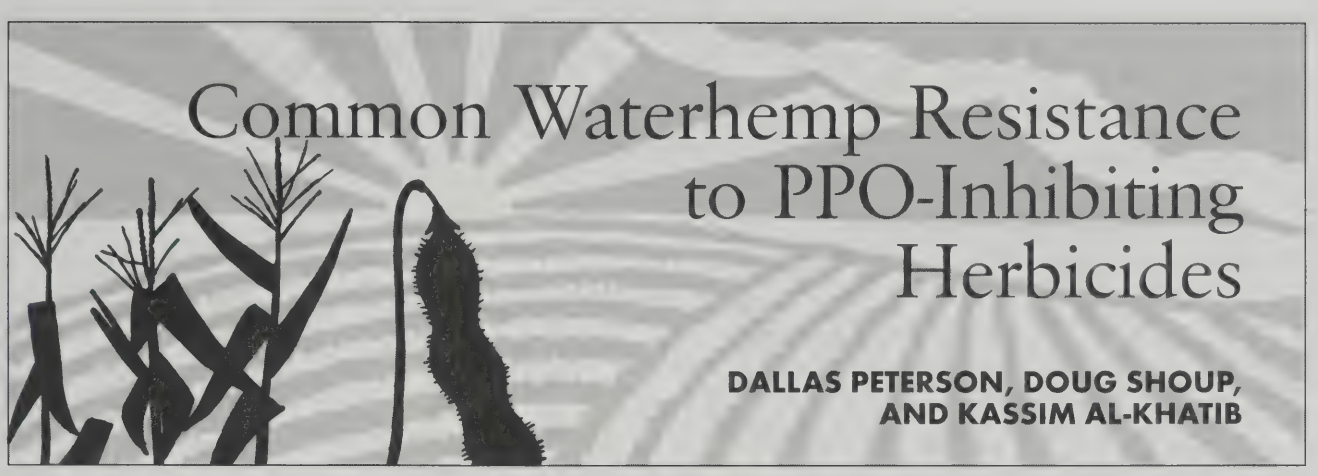
A strip-plot statistical design with four replications is used at each research location. Herbicides and hybrids are equally weighted sub-plots in this type of design. Strip-plots allow practical use of farm-scale equipment for small plot research. Although visual injury is recorded from 1 to 2 wk after application, the primary type of data used to identify treatment differences is grain yield. Yield from each location is individually subjected to analysis of variance statistical procedures. Analysis of variance is a common statistical tool in agronomic research and is used to understand sources of variability. Yield averages for specific herbicide by hybrid combinations are separated when appropriate using least-significant difference procedures. These types of statistical tools are used to interpret and ultimately present data for specific hybrids to growers.

## DATA PRESENTATION

Once a herbicide by hybrid combination has been tested for at least 2 yr at multiple locations, a risk category is determined for each combination. Herbicide by hybrid combinations in the least risk category exhibit good herbicide tolerance and produce maximum yields. The risk of yield loss is unlikely under normal environmental conditions. Herbicide by hybrid combinations are rated as standard risk when injury and yield loss are expressed in some instances. These losses usually occur under adverse environmental conditions or unusual circumstances such as drought or greensnap. Application management is

recommended with herbicide by hybrid combinations that show consistent low-level reductions in yield. Research has shown application timing to be the most effective management option to reduce the risk of potential yield loss. If a herbicide causes consistently large yield loss for an individual hybrid, that particular herbicide by hybrid combination will not be recommended for use.

Research that tests the effect of herbicides on specific hybrids provides seed companies and farmers with an expanded knowledge base of an important crop input to help maximize yield. In addition, this information can be used to help customers make informed decisions about their weed management options.



# Common Waterhemp Resistance to PPO-Inhibiting Herbicides

**DALLAS PETERSON, DOUG SHOUP, AND KASSIM AL-KHATIB**

Common waterhemp has become a troublesome weed in many midwestern states over the past several years. It competes strongly with crops, interferes with harvest, and reduces crop yield and quality. Low densities of common waterhemp are known to reduce yield in soybean. When it emerges with a soybean crop, common waterhemp at eight plants per meter of row reduced soybean yields up to 56% (Bensch et al., 2001).

Acetolactate synthase (ALS)-inhibiting herbicides such as Pursuit, Scepter, Pinnacle, and Synchrony STS provided good control of common waterhemp when initially introduced on the market. However, due to their widespread use, resistant waterhemp populations quickly developed. Protoporphyrinogen oxidase (PPO)-inhibiting herbicides such as Blazer, Cobra, Reflex, and Flexstar provided good waterhemp control, and thus these herbicides were integrated by many farmers into their weed control programs to help manage the ALS-resistant waterhemp. With the introduction of Roundup Ready soybean, the reliance on both ALS-inhibiting and PPO-inhibiting herbicides has been dramatically reduced, but continues to be used on conventional soybean varieties.

Kansas State University was contacted in summer 2000 to investigate a report of poor waterhemp control with Blazer in a soybean field near Sabetha in northeastern Kansas. The field had been in continuous soybean for many years, with Blazer applied for four consecutive years starting in 1997 (Table 1). A field experiment was established at the Sabetha site after two initial Blazer treatments earlier in the season had not provided adequate control. The experiment consisted of three application rates of Blazer and Cobra, representing 0.5, 1, and 2× typical field use rates applied to 6- to 12-inch waterhemp. Weed control was evaluated 1 wk after treatment. Although treated waterhemp exhibited some injury symptoms in the form of chlorosis and minor necrosis, plants were not killed and control was much lower than expected (Table 2).

Waterhemp seed was collected from the field with suspected PPO-resistant plants at the end of the 2000 growing season to conduct dose-response studies in the greenhouse. Susceptible and resistant biotypes of common waterhemp were treated with Blazer, Cobra, Reflex, Authority (post), Gramoxone, Roundup, Pursuit, and Harmony GT. Plants were grown in the greenhouse until they reached a height of 5 inches and then were treated

**Table 1. History of herbicide use in soybean field with PPO-resistant common waterhemp.**

| Year | Crop | Herbicide Use |
|---|---|---|
| 1996 | Soybean | Pursuit |
| 1997 | Soybean | Pursuit + Blazer |
| 1998 | Soybean | Pursuit + Blazer |
| 1999 | Soybean | First Rate + Blazer + Poast Plus |
| 2000 | Soybean | Classic + Pinnacle, fb Basagran + Blazer+ Poast Plus, fb Blazer, fb Blazer |

**Table 2. Common waterhemp control with Blazer and Cobra at Sabetha, KS.**

| Herbicide | Rate (oz/acre) | Waterhemp Control (%) |
|---|---|---|
| Blazer | 8 | 7 |
| | 16 | 13 |
| | 32 | 22 |
| Cobra | 6 | 20 |
| | 12 | 23 |
| | 24 | 28 |
| LSD (0.05) | | 6 |

with 0, 1/8, 1/4, 1/2, 1, 2, 4, and 8× the normal use rates of each herbicide.

Results from greenhouse experiments confirmed resistance to PPO-inhibiting herbicides, in addition to resistance to the ALS-inhibiting herbicides. Dose-response curves for susceptible and resistant waterhemp biotypes to Blazer, Cobra, Reflex, and Authority are presented in Figures 1-4. The magnitude of resistance was greater for Blazer and Cobra than for Reflex or Authority, but cross-resistance occurred among all four herbicides.

Field experiments were conducted in 2001 at the Sabetha site to evaluate herbicide options for control. The field is unique because it consists almost entirely of common waterhemp, with very few other weed species present. Results in 2001 were similar to the previous field and greenhouse results, because poor waterhemp control was achieved with the PPO-inhibiting herbicides. However, Authority preemergence at 5.3 oz/acre still gave good control of the resistant biotype of common waterhemp. Products such as Dual Magnum, Sencor, Domain, and glyphosate, which are not PPO- or ALS-inhibiting herbicides, controlled the waterhemp as expected. However, due to the extremely high waterhemp populations, sequential programs were often required to provide acceptable season-long waterhemp control.

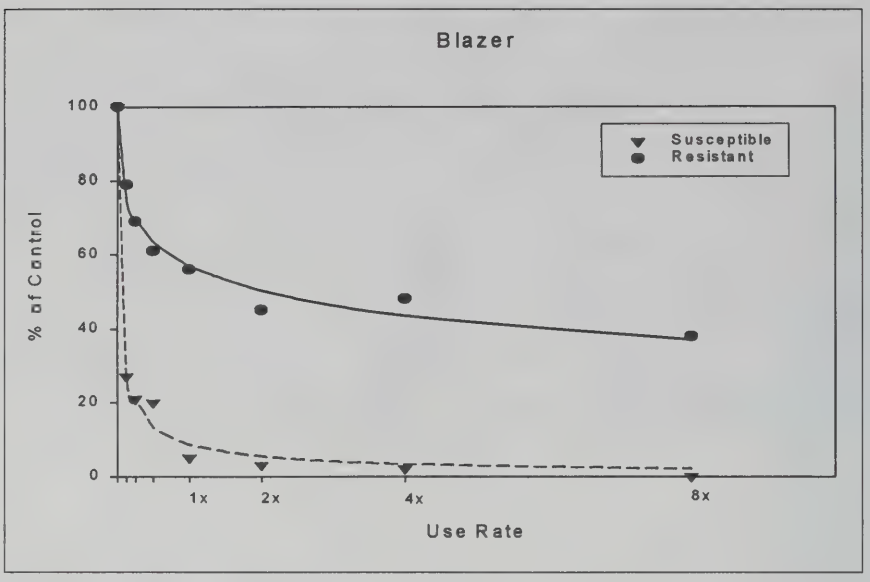



**Figure 1. Dose response of susceptible and resistant waterhemp biotypes to foliar applications of Blazer.**

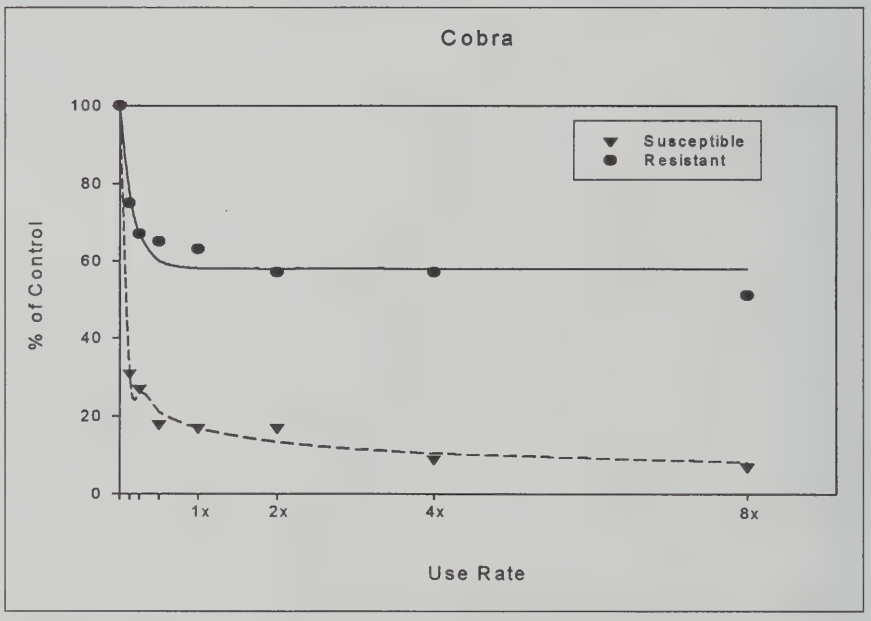



**Figure 2. Dose response of susceptible and resistant waterhemp biotypes to foliar applications of Cobra.**

These data represent the first confirmation of PPO resistance in common waterhemp. Occurrence of PPO-resistant waterhemp may have been observed earlier if the use of PPO-inhibiting herbicides had not decreased during the past 5 yr due to the increased use of Roundup Ready soybean. The impact of PPO-resistant waterhemp would have been much greater without the introduction of Roundup Ready technology. However, the discovery of PPO resistance still has major implications because several companies are evaluating new experimental herbicides with the PPO-inhibiting mode of action, and concerns have been raised about waterhemp control with glyphosate.

## REFERENCES

Bensch, C.N., M.J. Horak, and D.E. Peterson. 2001. Amaranthus competition in soybeans. Proc. North Cent. Weed Sci. Soc. 55: 81.

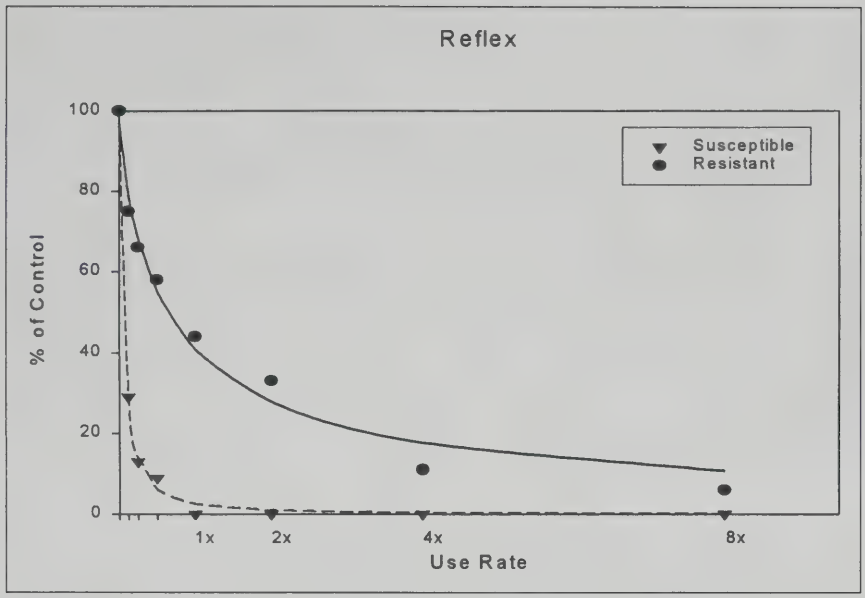



**Figure 3. Dose response of susceptible and resistant waterhemp biotypes to foliar applications of Reflex.**

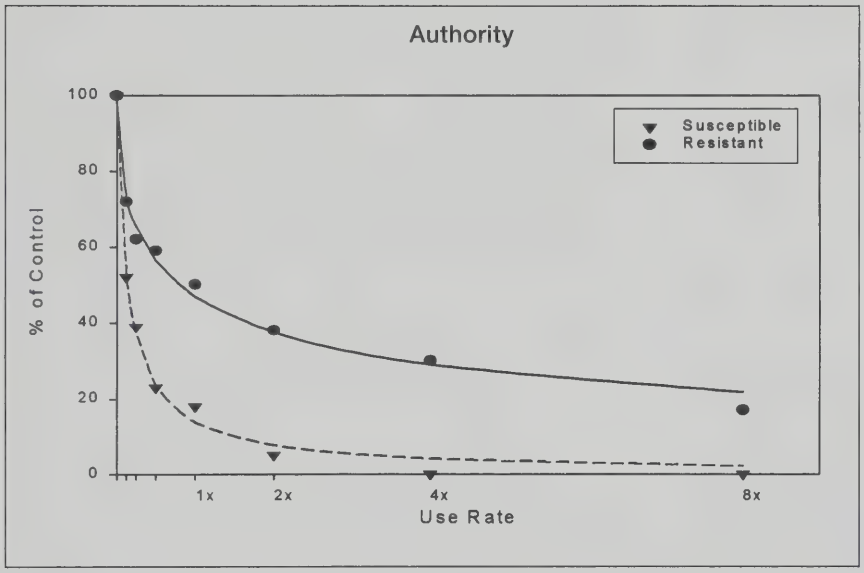



**Figure 4. Dose response of susceptible and resistant waterhemp biotypes to foliar applications of Authority.**

# Dealing with Common Pokeweed in No-Till Corn and Soybean Production

J. D. GREEN

## INTRODUCTION

Common pokeweed (*Phytolacca americana* L.) is a warm-season perennial that grows well in nondisturbed areas such as fencerows, roadsides, and woodland borders. Because of its ability to propagate in undisturbed sites, it has become an increasing concern in corn and soybean fields that have been managed under continuous no-till crop production practices. The large taproot that is characteristic of common pokeweed and its growth habit make this weedy plant a challenge to control when tillage practices are limited. The green leaves, fleshy stems, and purple berries of common pokeweed can inhibit the harvesting process and lead to discounts at the elevator for high moisture and stained seed.

Common pokeweed is a deep-rooted plant that is native to North America. It reproduces from buds on the root or from seeds. Aboveground shoots of this plant that arise from the taproot consist of diffusely branched, fleshy stems (resembling a small tree) that can reach heights of 6 to 8 ft under fertile conditions. The fruit produced in late summer are a cluster of green berries that turn purple to black at maturity and contain a profuse amount of red juice that can stain harvested crop seed. Numerous bird species are known to feed on the berries and are capable of randomly dispersing pokeweed seeds over sizeable areas. New plants from seed dispersed on undisturbed sites, such as no-till crop fields, are capable of becoming more entrenched as their taproots develop.

Many plants that form taproots generally do not tolerate intensive tillage practices. Therefore, common pokeweed is generally not a problem in crop fields that are exposed to between-crop tillage. In fact, one of the most effective methods to combat this weed species is use of mechanical controls such as moldboard plowing and discing. However, reducing tillage has become a desirable practice for corn and soybean producers to help reduce soil erosion, to decrease energy and crop production costs, and to save time during the planting season. Therefore, alternative or chemical control methods are more desirable.

Field studies have been conducted in Kentucky to evaluate the effectiveness of postemergence herbicides on common pokeweed in no-till corn and soybean production systems. Other studies were designed to evaluate cultivation for control of common pokeweed in a no-till production system. The equipment industry has developed cultivators with large sweeps capable of operating between crop rows in no-till plantings with minimal disturbance to stubble and plant residue at the soil surface. These cultivators are called "conservation tillage cultivators" and are intended to operate at shallow depths to cut plants below the soil surface. These studies compared the effectiveness of in-season cultivation with a John Deere 886 Conservation Tillage cultivator with and without a postemergence herbicide application.

## CORN

Herbicide products evaluated for use in corn have included dicamba (Banvel, Distinct) and acetolactate synthase (ALS)-inhibiting active ingredients that are found in Accent, Basis Gold, Beacon, Permit, Exceed, Spirit, and Lightning. The best season-long suppression of common pokeweed growth each year (approximately 60 to 80% shoot inhibition) was observed with Banvel, Lightning, and Exceed. Beacon and Permit provided some initial activity on pokeweed shoots, but significant regrowth was observed. Accent and Basis Gold provided very little control of shoot growth. Spirit herbicide (a 3:1 ratio of primisulfuron:prosulfuron) provided control similar to Beacon (primisulfuron), but was less than the effective-

**Table 1. Guide to common pokeweed response to postemergence herbicides in corn and soybean.[a]**

| Herbicide | Crop | Effectiveness Rating |
|---|---|---|
| Accent | Corn | 3 |
| Basis Gold | Corn | 5 |
| Banvel | Corn | 7 |
| Beacon | Corn | 5 |
| Clarity | Corn | 7 |
| 2,4-D | Corn | 5 |
| Distinct | Corn | 7 |
| Exceed | Corn | 7 |
| Glyphosate (RR-crops)[b] | Corn, Soybean | 8 |
| Lightning (CLEARFIELD)[b] | Corn | 7 |
| Marksman | Corn | 7 |
| Permit | Corn | 5 |
| Raptor | Soybean | 5 |
| Roundup UltraMAX (RR-crops)[b] | Corn, Soybean | 8 |
| Spirit | Corn | 6 |
| Synchrony STS (STS-soybean)[b] | Soybean | 5 |
| Touchdown (RR-crops)[b] | Corn, Soybean | 8 |

Good, 8 to 9; fair, 6 to 7; and poor, <5.

[a] Effectiveness of in-season herbicide treatments on perennial broadleaf weeds often provides only partial control or suppression. The response value indicated is based on a numerical scale from 0 to 9 comparing the relative effectiveness of the herbicides.

[b] Apply only on selected field corn hybrids designated with GENETIC resistance/tolerance to imidazolinone herbicides (CLEARFIELD hybrids); to Roundup Ready (RR-corn or RR-soybean); or to sulfonylurea-tolerant soybean (STS-soybean). Consult the label for guidelines and specific directions.

ness observed with Exceed (a 1:1 ratio of primisulfuron:prosulfuron).

Postemergence applications of Exceed and Banvel also have been evaluated with and without an in-season cultivation by using a conservation tillage cultivator. Cultivation was made 1 wk after a postemergence herbicide application. Common pokeweed growth was suppressed in areas treated by 40 to 60% when cultivation was used without a postemergence herbicide. In general, acceptable control was observed between the corn rows where cultivation occurred, but no control was obtained in or near the corn rows.

In cultivation studies postemergence herbicide applications of Exceed and Banvel without cultivation were shown to be effective in suppressing common pokeweed growth. However, cultivation after an Exceed treatment further enhanced common pokeweed control in three of four field studies. Banvel followed by cultivation enhanced common pokeweed control early in the crop season, but cultivation did not seem to greatly improve control when evaluated later in the season compared with Banvel without cultivation.

In fields heavily infested with common pokeweed corn grain yield was reduced in nontreated check plots. This trend indicates that there is a potential for common pokeweed to reduce grain yield when control measures are not implemented. The use of herbicides alone had a greater tendency to reduce the likelihood of corn yield loss compared with cultivation alone.

## SOYBEAN

Herbicide options available in soybean that are known to have activity on common pokeweed are much more limited. Initial observations in field studies with two ALS-type herbicides, Synchrony STS and Raptor, indicated slight suppression of common pokeweed, but provided poor results later in the season. In-season postemergence applications with glyphosate (i.e., Roundup Ultra) in Roundup Ready soybean were more effective (70 to 80% control). However, poor results on pokeweed have been observed with Roundup Ultra when applied as a "burndown" treatment before planting soybean.

Cultivation studies also have been conducted after applications of Roundup Ultra and Synchrony STS. Cultivation treatments without herbicides provided less than 50% common pokeweed control. As noted with the corn studies, acceptable control was observed between the rows where cultivation occurred, but no control was obtained in or near the soybean row. In addition, pokeweed had more of an opportunity to have a height advantage because soybean is a lower growing plant. Synchrony STS followed by cultivation provided 70 to 80% pokeweed control in two different field studies, whereas Roundup Ultra with and without cultivation provided greater than 90% control.

## SUMMARY

Few herbicides are known to effectively suppress common pokeweed in continuous no-till corn and soybean production systems. Although Exceed and Banvel (i.e., dicamba) were effective in suppressing pokeweed growth in corn, herbicides designed for use on herbicide-tolerant crops offer other choices to consider. These herbicide options include glyphosate products (e.g., Roundup UltraMAX, Touchdown) labeled for use on Roundup Ready corn and soybean or Lightning on Clearfield corn hybrids.

Between-crop tillage is another control method to reconsider. However, intensive mechanical control methods may be a less desirable option in fields where previous crop residue must be maintained for soil erosion control. On the other hand, cultivation with a conservation tillage cultivator may offer some help toward curtailing growth of plants that emerge from deep taproots. Most of the benefits with cultivation alone would be between the crop row with little impact on pokeweed plants growing in or near the crop row. Therefore, best results could be achieved with a postemergence herbicide treatment followed by cultivation. An additional limitation in soybean, is that row spacing has become increasingly more narrow (i.e., less than 30-inch rows), making cultivation an impractical option in soybean production.

# WeedSOFT℠: A New Approach to Weed Management Decisions

**CHRISTY L. SPRAGUE**

Weed management can be one of the most challenging decisions that growers and their advisors face from year to year. Good weed management tactics need to take into account efficacy, economics, and environmental stewardship. Each year growers are faced with new herbicides, name changes, and premixes. The sheer number of products that is available on the market adds to the confusion. With all these considerations it is extremely hard to make a decision. Computer models are well suited to process these large quantities of information and therefore may help facilitate the weed management decision process.

WeedSOFT℠ is a decision support system (DSS) designed to assist growers, consultants, and extension educators in making weed management decisions (Mortensen et al., 1999). This interactive software is a bioeconomic (threshold-based) model that was developed and is currently being used in Nebraska by more than 500 crop consultants and farmers. Over the past 2 yr there has been an effort to regionalize this software. Weed scientists from Nebraska, Kansas, Missouri, Wisconsin, Michigan, Indiana, and Illinois have partnered to make this a reality. This year WeedSOFTSM will be introduced in Illinois.

## DIFFERENT VERSIONS

In regionalizing the software weed scientists quickly became aware of the different cropping practices, rotational and environmental restrictions, and weed problems among the states. The basic principles of WeedSOFT℠ are the same for all states; however, each version of WeedSOFT℠ is customized for individual states. For example, herbicide recommendations and environmental restrictions for Illinois are very different than those for Nebraska. Weed competition indices are also very different for these two states. In Illinois, giant ragweed is considered the most competitive weed species. In Nebraska, however, giant ragweed competition is equivalent to common lambsquarters with common sunflower being the most competitive species. Growing conditions and weed genetic variability may in part explain these differences.

## FUNCTIONS OF WEEDSOFT℠

There are two modules incorporated in Illinois' version of WeedSOFT℠: 1) ADVISOR, and 2) WeedVIEW. WeedVIEW is a picture database that offers detailed photographs of more than 35 weed species to help aid in weed identification. The heart of WeedSOFT℠ is ADVISOR. It is the diagnostic and analytic decision support component of the software.

## HOW DOES ADVISOR WORK?

The user defines crop, soil moisture, climate, and numbers and types of weeds. ADVISOR analyzes these contributing conditions and assists the user in the selection of optimal weed control treatments. ADVISOR incorporates soil-applied, postemergence, and sequential programs to strategize a weed management plan. ADVISOR ranks the list of allowable weed control options in descending order of percentage of maximum yield or in descending order of net gain. ADVISOR accomplishes this task by calculating expected yield loss for a given weed population through a series of equations, taking into account expected crop yield, weed species competitive ability, crop competitiveness, and herbicide efficacy (Nesser et al., submitted). Through these calculations ADVISOR also can calculate the dollars lost if the field is not treated.

WeedSOFT[SM] is a decision support system not a decision maker. It broadens the various weed management strategies from which a grower can choose. In addition, WeedSOFT[SM] is an excellent educational tool for learning more about the competitiveness of weed species grown in different crops under a variety of conditions.

## REFERENCES


Mortensen, D.A., A.R. Martin, F.W. Roeth, T.E. Harvill, R.W. Klein, M. Milner, G.A. Wicks, R.G. Wilson, D.L. Holshouser, D. Lyon, P.J. Shea, and J.T. Rawlinson. 1999. WeedSOFT[SM] (version 4.1). Department of Agronomy, University of Nebraska, Lincoln, NE.

Nesser, C., J.A. Dieleman, D.A. Mortensen, J.T. Rawlinson, and A.R. Martin. 2000. WeedSOFT[SM]: a state of the art weed management decision support system. *Weed Technology* (submitted).

# Insect Vectors of Plant Pathogens: Implications for Crop Protection

**DAVID RAGSDALE**

An insect-vectored pathosystem presents a level of complexity beyond that of the classical disease triad of susceptible host, viable inoculum, and favorable environment. Adding the insect vector introduces another biological entity into the pathosystem. For insect-vectored viruses, the virus is an obligate parasite and infection of new hosts is wholly dependent upon insects for dissemination. Most insects that transmit or "vector" plant pathogens are Hemiptera (sucking insects) with a majority of known plant viruses being transmitted by just a few families of Hemiptera, aphids, leafhoppers, whiteflies, and planthoppers. A few beetles and other insects can vector plant pathogens but they are far less important than the Hemiptera. Transmission characteristics of aphid- and leafhopper-vectored pathogens vary from nonpersistent, stylet-borne to persistent, circulative. For nonpersistent transmission, once virus is acquired the vector is immediately capable of transmission, but it remains infective for only a few minutes to hours. In persistent, circulative transmission, there is a period of time after virus is acquired before the insect is capable of transmitting virus. Once this latent period has passed, the insect remains infective for hours, or even its lifetime. Strategies to control the spread of insect-vectored pathogens are highly dependent upon method of transmission, availability of inoculum, movement of the vector in the environment, and vector presence when hosts are most susceptible. Control of insect-vectored pathogens can be preventative (cultural) or therapeutic (insecticides), and the most appropriate strategy depends on the transmission characteristics of the pathosystem.

# Herbicide Behavior in the Soil Environment

**BILL SIMMONS**

Herbicides with soil activity are still an important component of weed control in corn and soybean. Such herbicides may include both preapplied herbicides and post-applied herbicides with soil activity. The interaction of soil properties, water, and application timing affects efficacy, crop response, and potential for carryover. In this presentation, I discuss the following topics: basics of soil interactions with herbicides; value of residual control in total post systems; behavior of "new herbicides" in the soil; and carryover potential as affected by herbicide, soil, and climatic conditions.

Soils contain the organic matter and clay particles that control herbicide sorption and water relations, and provide the environment that influences microbial activity. The primary herbicide loss pathways in soil are microbial breakdown and chemical breakdown, primarily driven by reactions with water. The effects of soil temperature and moisture on herbicide degradation are straightforward in that degradation mechanisms that involve microorganisms operate best at optimum biological growth conditions. In addition, nonbiological chemical reactions are typically enhanced with increased temperature. Water is essential for microbial activity and increases aerobic processes until saturation occurs and gas transfer with the atmosphere is hampered.

Soil texture and organic matter content have a surprisingly small effect on carryover because the differences in water and nutrient availability are often counterbalanced by the difference in herbicide adsorption. Thus, a fertile soil, rich in organic matter, may promote faster degradation of a herbicide but also have less available to degrade based on its greater number of adsorption sites.

Soil pH is important in affecting the stability of some herbicides and herbicide families. High soil pH associated with calcitic soils, over-liming, or proximity to limestone gravel lanes may reduce herbicide degradation and increase carryover, which may be important for trains and some sulfonylureas. Hydrolysis, an important breakdown mechanism, slows significantly at soil pH near 7.0.

Biopersistence, or the ability of the parent compound to exist in the soil, is an important feature of soil-applied and some postemergence herbicides and determines the suitability of early preplant applications, residual weed control, and threat of off-site loss to surface or groundwater. To optimize the application timing of soil-applied herbicides, a balance between persistence and requirement for rainfall needs to be considered.

The soil-applied Acetamide market in corn is still a significant and competitive marketplace where performance profiles across application timings determine use and market share. In the past few years, two new herbicides have been introduced: Axiom by Bayer Corporation (flufenacet and metribuzin) and most recently Degree by Monsanto (formerly MON 58430, encapsulated acetochlor). Dual Magnum is the active isomer of metolachlor and allows for a lower use rate than the "old" Dual. BASF also has purified an active isomer of dimethenamid (Frontier/Outlook) that allows its use rate to be lowered while obtaining the same efficacy. These developments are the most recent ones in the marketplace. Future changes in the use patterns of these herbicides may occur in transgenic corn, in mixes with isoxaflutole and similar herbicides, and in formulations that allow post-application of these herbicides.

Herbicide persistence is an important property of soil-applied herbicides and some postemergence herbicides that allows for extended weed control. If a herbicide remains unaltered in the soil during the crop season of application, it is an advantage. If a herbicide remains in the soil and is present when a rotational (and susceptible) crop is planted the persistence causes herbicide carryover. Most herbicides **do not** carryover. Degradation rates in

the soil under normal environmental conditions typically reduce herbicide concentrations to sublethal levels for rotational crops. Some herbicides offer additional safety in that they are not injurious to rotational crops.

Shifts in herbicide application timing to earlier applications have put a premium on herbicide persistence to coincide with weed emergence. Generally, the resistance to degradation and downward movement within the soil profile are both important to obtaining satisfactory weed control.

Glyphosate-resistant soybean treated with glyphosate alone does not allow for any residual control of weeds that might germinate after the last post-application is made. What is the value of a residual herbicide either mixed with glyphosate or applied to the soil at planting? Data are presented that address this issue.

# Drainage Management for Water Quality and Agricultural Production Benefits

**DON PITTS**

Illinois is one of the most productive agricultural areas in the world. In many parts of the state, this productivity relies heavily on the practice of drainage. There are approximately 10 million acres of drained farmland in Illinois. Most of this land is drained with subsurface tile. Due to naturally high water tables, these soils need drainage for economical crop production. Drainage is practiced to ensure trafficable conditions for seedbed preparation, planting, harvesting, and other field operations. It also is practiced to reduce crop stress from excess water within the root zone after periods of high rainfall.

Although drainage is essential for economic crop production in many areas, there have been some significant environmental costs resulting from this practice. Subsurface drainage systems tend to intercept nutrient-rich soil-water and shunt it to surface water. Data from numerous studies have shown that a significant amount of the total nitrogen load to the Mississippi River from Illinois is being delivered to surface water from tile drainage systems. High nitrate levels also have been detected in public water supplies in some areas. Furthermore, studies have suggested that nitrogen enrichment is the main cause of the hypoxic zone in the Gulf of Mexico.

Drainage management (sometimes called controlled drainage) has been practiced for many years on organic soils to minimize subsidence, but it is also applicable to mineral soils. During the fallow season in Illinois, tile drainage removes significant amounts of nitrate from farm fields. Drainage is not needed at this time, so there is an opportunity to reduce this form of nitrogen loss during the time of the year that crops are not in the field.

Tile-drain systems are typically constructed without any control mechanisms and allow the soil to drain whenever the water table is above the elevation of the tile outlet. If control devices were retrofitted to existing tile systems, drainage management could be practiced. Drainage management allows for drainage outlets to be set at levels between the ground surface and the drain outlet. The water table could be allowed to rise during the fallow season, which would result in substantial water quality benefits. Also, raising the water table after planting can keep water and nutrients available for plant use during the growing season, representing another major production benefit.

The objective of this presentation is to describe how to design, install, and manage drainage systems to provide water quality and agriculture production benefits. Hydrologic principles, computer simulations, and field experiences are used to show how drainage management can decrease nitrate loading to streams and potentially decrease stress or damage to crops during dry periods. This practice can have important benefits for Illinois agriculture.

# Gaining Perspective on Biotechnology-Driven Seed Issues

**DENNIS THOMPSON AND DOUG MILLER**

Initial commercialization of the RoundupReady® herbicide tolerance trait for soybean (*Glycine max*) occurred in 1996. More recently, as a result of unintentional introduction of the Cry9C (StarLink®) insect resistance trait for corn (*Zea mays*) into the human food supply chain in 2000, society has become increasingly sensitive to the use of biotechnology in the agricultural seed industry. Many scientific, industry, and public discussions continue to be devoted to this issue. In the context of seed certification and from the perspective of seed certification administration, we explain the core concepts embodied in the two officially recognized seed certification systems used in the United States: Association of Official Seed Certifying Agencies (AOSCA) and Organization for Economic Cooperation and Development (OECD). The International Seed Network Initiative (ISNI), which was introduced to deal with the adventitious presence of genetically modified materials in conventionally developed seed, is explained. Current AOSCA research findings from a major national study that investigated adventitious pollen intrusion into hybrid maize seed production fields in 1998–2000 are presented. Practical advice is offered related to developing functional identity preserved grain systems, based upon the AOSCA Identity Preserved Program model. The ongoing controversy over seed purity, i.e., freedom from the adventitious presence of undesired seed, is complex and likely to continue in the foreseeable future. We want to ensure future discussions on this issue are considered in the proper context with respect to the official seed certification systems used in the United States.

# Digital Imaging: Get the Right Picture

**DENNIS BOWMAN AND ROBERT BELLM**

Digital cameras are becoming a standard crop-scouting tool. Images of plant and pest problems can be sent over the Internet to experts around the world for diagnostic assistance. This accelerated information transfer means a more timely pest management decision that may save crop quantity and quality. Using the Internet also saves the frustration of mailing a sample and finding out that by the time it reached its destination, it had deteriorated past the point of recognition.

The accuracy of a diagnosis from images is directly related to the quality of the images. Both the photographic quality and the image content are important. Focus, framing, and lighting are some characteristics of photo quality. With a little practice, almost anyone can take high-quality pictures with today's digital cameras.

For an accurate and fast diagnosis the correct content in the images is necessary. The correct range of images is also critical. From shots of the field that show patterns to close-ups of specific anatomical structures, a series of pictures gives the diagnostician the best information on the situation. Insects, weeds, and disease all have different sets of characteristics that are critical for diagnosis.

This workshop covers some of the characteristics that facilitate a rapid and accurate diagnosis. It draws on the more than 2,000 digital samples that have been sent to the University of Illinois' Distance Diagnostic system for examples and practical tips for "Getting the Right Picture."

# Understanding Armyworm Outbreaks: Echoes from the Past

**RICK WEINZIERL**

In summer 2001, outbreaks of the armyworm, *Pseudaletia unipuncta* (Haworth) (Lepidoptera: Noctuidae), occurred in many areas in Illinois and other midwestern and northeastern states. Infestations originated primarily in fields of small grains–almost entirely wheat–and in grass pastures. After nearly fully grown larvae ate all the foliage in these initial locations, they moved, en mass, to nearby cornfields, in some instances eating plants to the ground.

## SOME NOT-SO-RECENT HISTORY

Although it had been several years since anyone had seen an armyworm outbreak of the magnitude witnessed in 2001, the armyworm is **not** a new pest, nor is it a product of modern approaches to agriculture. A quick review of its recorded history substantiates this assertion. Let's start the review "in the middle"–approximately 140 yr ago–because from an Illinois entomologist's perspective, the most notable outbreak of the armyworm undoubtedly occurred in 1861. The first two state entomologists of Illinois, Benjamin Walsh and Cyrus Thomas, debated its life history on the pages of the 1861 *Prairie Farmer*, and the country's most famous economic entomologist of all time, Charles Valentine Riley, later discovered several important answers to questions posed in 1861 by these earlier investigators.

In summer 1861, armyworm populations reached devastating numbers in many locations in the eastern half of Canada and the United States, from southern Illinois (Wiley, 1861) to Ohio (Kirkpatrick, 1861; Klippart, 1861a), New York (Fitch, 1861), and New England (Riley, 1883, and references therein). A central Illinois farmer noted,

> "As to their number, they have been seen moving from one field to another three tiers deep. A ditch has been filled to the depth of three inches in half an hour. ... A worm was noticed to eat one square inch of corn leaf in 30 minutes. At this rate, if every stalk in a wheat field was occupied by a worm, every leaf would be destroyed in about six hours (Bartlett, 1861)."

This was not the first time that the armyworm had caused severe losses. In a summary of New England weather records from 1623 to 1854, Flint (1854) cited reports of numerous outbreaks. One account told of "millions of devouring worms (presumably lepidopteran larvae) in armies, threatening to cut off every green thing." Based on Flint's summary, Riley (1883) concluded that the first definite recorded occurrence of the armyworm in North America was in 1743, noting that previous accounts may have referred to other lepidopteran species. Nonetheless, Riley (1883) suggested that the "worms" of 1632, 1646, 1649, and 1662 were also possibly the armyworm. In an account of the infestation of 1770 (cited in Riley, 1883), an observer wrote:

> "They would go up the side of a house, and over it, in such a compact column that nothing of the boards or shingles could be seen. There were fields of corn on the meadows of Haverhill and Newbury, standing so thick, large, and tall, that in some instances it was difficult to see a man standing more than one rod in the field from the outermost row; but in ten days from the first appearance of this Northern Army nothing remained of this corn but the bare stalks!"

Between 1781 and 1860, armyworm outbreaks of local or regional severity occurred at least 20 times (Fitch, 1861; Walsh, 1861a; Wiley, 1861; Riley, 1883; Panton, 1897). In 1880, when armyworm populations exploded in the northeastern United States, the *New York Sun* (Anonymous, 1880) carried the following account:

> "A journey through a large part of Monmouth County revealed a singular state of affairs. ... the crops, for the most part, were withered and lifeless... In many places the road was literally covered with the worms, all in

> motion, and all moving towards the fields on either side. Thousands and tens of thousands were crushed beneath the wagon wheels and under the horses' feet; but the rest pressed on."

The twentieth century also brought several devastating outbreaks in both the United States and Canada (Baker, 1915, 1939; Knight, 1916; Moran and Lyle, 1940; Breeland, 1958; Guppy, 1961). Although modern insecticides, if applied in a timely manner, now can prevent catastrophic losses, the armyworm remains a pest of economic importance, as witnessed in 2001. Why? Even though we know a great deal more about armyworms now than the farmers and entomologists of the mid-1800s did, the same characteristics of this insect's life history that puzzled our predecessors still contribute to its ability to cause a great deal of injury before we detect it and control it.

## UNRAVELING THE LIFE HISTORY OF THE ARMYWORM

One hundred and forty years after the great outbreak of 1861, the life history of the armyworm seems to be well understood. Two or more generations develop annually in most areas in which it occurs, and overwintering success varies with climate zone and the severity of each individual winter. Although pupae are most likely to survive harsh winters, larvae and adults may overwinter during at least some years at the latitude of St. Louis and southern Illinois, and probably even further to the north. Long-distance migration from the south is known to reintroduce adult moths into Canada and northern portions of the United States where the species does not overwinter; such migrations also contribute to increased densities, broader age distributions, and longer periods of infestation in areas where overwintering does occur.

Although the life cycle of the armyworm now seems simple, in 1861, just as in 2001, infestations of nearly mature armyworms seemed to materialize overnight, then after destroying pastures, small grains, and corn, the species seemed to disappear. Dramatic outbreaks followed by years of scarcity made it difficult for early observers to determine the numbers of generations per year and the stage(s) in which the armyworm overwintered. Several factors that are now understood but were not clear to observers in the 1800s contributed to the mystery of the armyworm.

First, armyworm adults are often called "nondescript" because they are not brightly colored or distinctively marked. Coupled with their nocturnal habits, they were (and are) rarely observed, even when numerous. Consequently, the females who laid the eggs that would give rise to devastating outbreaks were not necessarily obvious, even preceding outbreaks.

Additionally, armyworm populations often crashed at about the time larvae were finishing their destruction of crops. Parasitism of large larvae by tachinid flies and parasitic wasps was often so great that exceedingly few or even no adults emerged from large numbers of pupae collected in infested fields. No heavy flight of any moths followed the maturation of larvae that had destroyed vast areas of crops. Consequently, even after the identity of the armyworm was widely known, observers wondered whether the normal sequence of events was for adults to emerge from pupae in midsummer and give rise to a second generation, or the majority of individuals wintered in the ground as pupae.

As noted in the summary of our modern understanding of the armyworm's life history, the species does not overwinter in all areas where it is observed in the spring or summer. Instead, adults may migrate long distances to repopulate areas where overwintering mortality was complete. Immigrant females also may lay eggs in areas where local, overwintered individuals give rise to a spring generation too, and the timing of immigration in relation to local development may result in a range of larval stages all being present at once, even in the first generation of the year. In the absence of tools to identify the occurrence of immigration from the south, in 1861 and for years thereafter, the simultaneous presence of very large and very small larvae of the same species confounded most explanations of what stage overwintered.

Observations of parasitism plus the broad range of larval stages present at once particularly puzzled John Klippart, an Ohio agriculturist. He saw very small parasitic wasp larvae exiting the bodies of fully grown armyworm larvae at the same time he saw very small armyworm larvae (barely larger than the parasitic wasp larvae) beginning their development. He incorrectly surmised that the large armyworm larvae were giving birth to young armyworm larvae (Klippart, 1861b). This triggered the wrath of Benjamin Walsh (1861b), who wrote the following:

> "So little indeed are the laws of Natural History understood in this country, that ... 'a naturalist in a western paper gravely states that this caterpillar may be viviparous, and may give birth to living baby caterpillars, which also, in due time, follow the great law of nature, and likewise become happy mothers to another caterpillar brood.' Yes, and lambs may produce lambs, and calves may generate calves, and little girls of five years old may be mothers of fine thriving families. One event is every whit as likely, and every whit as possible, as the other."

What transpired in the process of trying to understand the life history of the armyworm, beginning in 1861, was in many ways the beginning of extension entomology in Illinois. In June of 1861, the *Prairie Farmer* published a letter from Cyrus Thomas (1861a). He admitted to submitting his thoughts a little prematurely and with insufficient data, but he reasoned that the severity of the season's armyworm outbreak demanded that he communicate whatever information he could. He noted that newly hatched larvae appeared over a period of several weeks from late April until mid-May in the far southern portions of Illinois. He suggested that the females laid their eggs on the stems of grasses early in the spring, and that the larvae that destroyed grasses and grain crops in May and June would pupate and produce another flight of moths. These adults would give rise to a second brood of larvae later in the season, and this second generation, he hypothesized, would overwinter as pupae.

In July 1861, Thomas (1861b) reported that burning meadows and fields in the fall or winter seemed to ameliorate armyworm ravages during the subsequent growing season. These and similar reports would prove very important to Walsh, who also studied the armyworm that summer. In September, Walsh (1861c) published a lengthy piece on the armyworm that began with a confident decree:

> "The practical result of the following passages may be expressed in very few words: *Burn your tame grass meadows over annually, in the dead of the year, and get your neighbors to do the same, and you will never more be troubled with the army worm.*"

Based in part on earlier reports (Thomas, 1861c) and because he and others had observed armyworm infestations originating in perennial grasses, Walsh (1861a,c,d) reasoned that eggs deposited there represented the overwintering stage and that burning pastures and prairies in the winter would kill them. The apparent absence of later generations of larvae (after a spring or early summer outbreak) led Walsh to believe that the species was univoltine (one generation per year).

By fall 1861, the armyworm outbreak had ended throughout eastern North America, but Walsh and Thomas would argue their respective opinions about its life history through the close of the year. Significant observations seemed to contradict Walsh's strongly held notion that armyworms overwintered in the egg stage. For example, Thomas (1861b) noted that, in southern Illinois, the initial appearance of larvae occurred in wheat as often as meadows, and the wheat was not present in the field for egg-laying in midsummer when Walsh argued that the overwintering eggs were laid. Thomas did, however, note that few of the first-generation larvae and pupae that he had collected produced adult moths (Thomas, 1861c), which caused him to alter (incorrectly) his earlier view and suggest that pupae of the first (and only) generation passed the winter.

Walsh did not agree with Thomas, and in response to a report from "an intelligent fruit grower" that meadows burned in the winter had indeed had escaped infestation, he wrote (Walsh, 1861d):

> "This fact appears to me to finally settle the question between Mr. Cyrus Thomas and myself, as to the army worm moth, that lays the eggs for the May and June crop of armyworms, not coming out of the ground until the opening of the spring. If this were actually the case ... the burning over meadows WHILE THE FROST WAS IN THE GROUND, could in no possible way have prevented a moth, which did not appear till March or April, from depositing its eggs on them; whereas, if, as I firmly believe, the armyworm eggs are laid some time in June, July or August, on the stems of the tame grass close to the ground, and lie dormant there till next spring, burning the meadows in the dead of the year, would be certain to destroy them."

Walsh had taken Thomas to task rather severely in his arguments about the armyworm's life history, and Thomas replied in mock offense (Thomas, 1861d) ...

> "I had no thought, while cautiously feeling my way along the entomological road, that I should meet with the deadly fire of masked batteries, or of heavy artillery mounted on prominent embankments. But so it is, the road is flanked by cannon of large caliber, which cast their shot, shell and grape, thick and fast around my unprotected head. It matters little to the farmers of Illinois which shall prove the better shot in the controversy between friend Walsh and myself. But the subject of the controversy is of vital importance to them; and this fact is my apology for my again bringing this subject before them. And I must say in all kindness to friend Walsh, that his spicy arguments savor rather too much of a desire to sustain a theory."

In the next issue of the *Prairie Farmer*, Thomas (1861e) continued defending his views. Walsh (1861c) had argued that the observations of nonscientists could not be trusted (although he himself often relied upon such reports). Thomas (1861e) responded by noting that MANY people in spring 1861 had observed numerous moths thought to be the armyworm, and he queried, "Now if these moths belonged to other species, what became of their progeny? ... The armyworm was soon afterwards abundant, but no other [species were]." Thomas noted yet again that the armyworm often made its appearance where there were no meadows and where

neither grass nor small grains grew the previous season. In answer to the question of why burning would provide any benefit if armyworms wintered as pupae and not eggs, Thomas offered, "... if a meadow is burnt, the young grass will scarcely be sufficiently advanced when the moths appear for them to deposit their eggs on it, as I think they appear quite early." This, in fact, was a very important deduction. Although it was correct, it did not convince Walsh.

In a lengthy letter published in the *Prairie Farmer* and riddled with sarcasm, Walsh (1861e) professed innocent dismay:

> "Friend Thomas: I must confess I was utterly confounded and bewildered by the first of those letters of yours on the army worm question which have recently appeared in the columns of the PRAIRIE FARMER. Referring to what I have published on the subject, you complain of 'the deadly fire of MASKED BATTERIES,' 'HEAVY artillery mounted on prominent embankments,' 'shot, shell and grape, thick and fast around my (your) UNPROTECTED HEAD,' and ... Why, if I had insinuated that you had feloniously abstracted certain moneys from the treasury of Jackson County, or accused you of embittering by infidelity the domestic facility of Mrs. T., you could scarcely have made use of much stronger language."

Walsh (1861e) admonished Thomas: "Shall I venture to tell you what I think is your besetting sin in scientific matters? You suppose that every one of your neighbors is as good an entomologist as yourself ..." Walsh proposed that the "moths" many people had reported seeing might have been mayflies. He insisted that armyworms likely moved from a timothy meadow to the grassy courthouse grounds in Thomas' home town, and, although he himself had never been there, Walsh (1861e) rather presumptively produced a map based on Thomas' (1861e) description of the locale.

Walsh and Thomas never resolved the questions that they raised about the life history of the armyworm. In a series of three articles under the heading "At the Tea Table" about the Walsh-Thomas fray, an anonymous author writing under the pen name June Isle poked fun at both of these soon-to-be imminent entomologists (Isle 1861a,b; 1862), and in 1865, the editor of the *Prairie Farmer* likewise held them to task for never following up on their theories with more detailed observations (Anonymous, 1865). Several years later, Charles Valentine Riley (who also got his start in entomology working with Walsh in Illinois and writing for the *Prairie Farmer*) would devote lots of attention to the armyworm in his nine "Missouri Reports" (Annual Reports of the State Entomologist of Missouri; see Riley 1870, 1876a,b; 1877). It was not until his eighth report and its addendum (Riley, 1876a) that he actually observed egg-laying and concluded that armyworms might overwinter in different stages at different latitudes.

Further knowledge of the armyworm's life history and distribution was slow to come ... it was 1914 before the idea of long-distance migration surfaced in the vaguest way in the literature (Baker, 1915), and it was 1955 when the opinion that outbreaks in Minnesota and Canada and other northern locales was dependent on the migration of armyworm moths from much further south (Aamodt, 1955). Finally, as the twentieth century neared an end, based on detection of pollen from a subtropical plant adhered to an armyworm moth captured in Iowa, Hendrix and Showers (1992) documented the distance involved in seasonal migrations ... the plant in from which the pollen grains originated is not found north of far southern Texas.

## SIGNIFICANCE OF IT ALL, IN THE TWENTY-FIRST CENTURY

In the 1860s and 1870s, the only methods available to reduce losses to the armyworm were to burn perennial grasses in the winter or spring and to dig trenches in front of the migrating "armies" of larvae. The actual value of burning was not well documented or understood, and better answers to questions about the life history of the armyworm seemed essential in devising more effective cultural controls. Walsh, Thomas, and Riley devoted a great deal of their energies to finding such answers, and in a time when superstitions were significant determiners of farming practices, Walsh and Thomas communicated the scientific observations and deductions they made clearly and directly to the public–farmers–through the pages of the most widely read periodical of the day the *Prairie Farmer*. (In the middle of the Civil War, the letters of Walsh and Thomas appeared in "the Farmer" alongside the text of speeches by President Lincoln.) Answers to questions about the armyworm were difficult to learn; these early entomologists had no light traps, pheromone traps, banks of weather data, or even budgets for travel to make observations. Notable, however, is that delays in understanding the armyworm's life cycle did not result from a failure of entomologists to communicate about it, frequently, in professional scientific publications and the agricultural press as well. One suspects that Walsh, Thomas, and others wrote so colorfully in part because they wanted to steer farmers away from unfounded, ineffective remedies toward their own scientifically based approaches. Even the mysterious June Isle echoed the call

for careful research on armyworm natural history. Although the celebrated naturalist Louis Agassiz (1863) upheld the traditional view that "... the man of science who follows his studies into their practical application is false to their calling," those contributing to the *Prairie Farmer* and numerous other farm periodicals had already concluded otherwise. The years following the Civil War saw an increase in mechanization, commercialization, and monoculture, creating an ever-increasing need for scientific solutions to agricultural pest problems (Sorensen, 1995). The letters of Walsh, Thomas, (and even Klippart) were the forerunners of today's extension publications. They were instrumental in teaching the farm public to think rationally about insect control, and they laid the groundwork built upon by Riley and his many successors, including those of us who work in Illinois today.

A small, historical sign stands near the site of Walsh's farmstead south of Cambridge, in Henry County, Illinois. It pays tribute to the first state entomologist of Illinois with the following words:

> "Benjamin Dann Walsh, Illinois State Entomologist from 1867 to 1869, was a pioneer in the application of insect study to agriculture. Born in England in 1808, he earned his Master 's Degree from Trinity College, Cambridge, England, in 1833. Though intended for the ministry, he chose the literary field and wrote for newspapers and magazines for several years. ... In 1838 he married Rebecca Penn and moved to the United States. From Chicago he moved to a farm near Cambridge where he remained for 13 years. In 1851 he moved to Rock Island and engaged in the lumber business until 1858. Thereafter he devoted himself to his longtime hobby of entomology and was soon recognized as a leader in the field. His first published entomological work appeared in 1860. In his lifetime he published 385 titles plus an additional 478 in collaboration with Charles V. Riley, another well known entomologist. Walsh contributed regularly to the Prairie Farmer, ... and was editor of The Practical Entomologist and co-founder of The American Entomologist with Riley. His private collection numbered 30,000 insects. His insect studies impressed scientists and perhaps more important, agriculturists. He was one of the first to advocate that farmers use scientific methods to control insects. His death on November 18, 1869, resulted from a railroad accident near Rock Island."

Farmers and entomologists in Illinois and the nation today are the beneficiaries of the "echoes from the past" associated with the armyworm.

## REFERENCES


Aamodt, T.L. 1955. Origin and development of 1954 Minnesota armyworm outbreak. *Proceedings of the Annual Meeting North Central Branch Entomological Society of America* 10: 51-52.

Agassiz, L. 1863. Methods of Study in Natural History. Ticknor and Fields, Boston. 319 pp.

Anonymous. 1865. The army worm. *Prairie Farmer* 32: 3-4.

Anonymous. 1880. Army worms. *New York Sun*, June 11 (cited in Riley, 1883.)

Baker, A.W. 1915. The army worm in Ontario in 1914. *Annual Report of the Entomological Society of Ontario* 45: 75-90.

Baker, A.W. 1939. Notes on the armyworm, *Leucania unipunta* Haw., outbreak in Ontario in 1938. *Annual Report of the Entomological Society of Ontario* 69: 96-99.

Bartlett, Dr. 1861. More about the army worm. *Prairie Farmer* 24: 3.

Breeland, S.G. 1958. Biological studies on the armyworm, *Pseudaletia unipuncta* (Haworth), in Tennessee (Lepidoptera: Noctuidae). *Journal of the Tennessee Academy of Science* 33: 263-347.

Fitch, A. 1861. The army worm moth. Boston Cultivator 23: 275-276.

Flint, C.L. 1854. Second Agricultural Rept., Massachusetts (cited in Riley, 1883).

Guppy, J.C. 1961. Life history and behavior of the armyworm, *Pseudaletia unipuncta* (Haworth) (Lepidoptera: Noctuidae) in eastern Ontario. *Canadian Entomologist* 93: 1141-1153.

Hendrix, W.H. III., and W.B. Showers. 1992. Tracing cutworm and armyworm (Lepidoptera: Noctuidae) northward migration using *Pithecellobium* and *Calliandra* pollen. *Environmental Entomologist* 21: 1092-1096.

Isle, J. 1861a. At the Tea Table: Loves Labor Lost: Sir Thomas vs. Sir Walsh. Chapter 1. *Prairie Farmer* 24: 373.

Isle, J. 1861b. At the Tea Table: Loves Labor Lost: Sir Thomas vs. Sir Walsh. Chapter 2. *Prairie Farmer* 24: 408.

Isle, J. 1862. At the Tea Table: Loves Labor Lost: Sir Thomas vs. Sir Walsh. Chapter 3. *Prairie Farmer* 25: 26.

Kirkpatrick, 1861. The army worm (*Leucania extranea*). *Fifteenth Annual Report of the State Board of Agriculture of Ohio*, 350-358.

Klippart, J.H. 1861a. The army worm. *Ohio Farmer* 10: 198.

Klippart, J.H. 1861b. The army worm question. *Field Notes* (30 Nov 1861).

Knight, H.H. 1916. The armyworm in New York in 1914. *Leucania unipuncta* Haworth. *Cornell University Agricultural Experiment Station Bulletin* 376: 751-765.

Moran, E.J., and C. Lyle. 1940. Observations on *Cirphis unipuncta* Haworth in Mississippi. *Journal of Economic Entomology* 33: 768-769.

Panton, J.H. 1897. Two insect pests of 1896. *Annual Report of the Entomological Society of Ontario* 27: 44-54.

Riley, C.V. 1870. The army worm, *Leucania unipuncta,* Haw., pp. 37-56, in Second Annual Report of the State Entomologist of Missouri.

Riley, C.V. 1876a. The army worm, *Leucania unipuncta* Haw., pp. 22-56, in Eighth Annual Report of the State Entomologist of Missouri.

Riley, C.V. 1876b. The army worm. Additional notes on the mode, place, and time of oviposition, pp. 182-185, in Eighth Annual Report of the State Entomologist of Missouri.

Riley, C.V. 1877. The army worm, pp. 47-50, in Ninth Annual Report of the State Entomologist of Missouri.

Riley, C.V. 1883. The army worm (*Leucania unipuncta* Haw.), pp. 89-156 (plus 5 plates), in Third Report of the United States Entomological Commission. U.S. Department of Agriculture, Washington, DC.

Sorensen, W.C. 1995. Brethren of the Net: American Entomology, 1840-1880. University of Alabama Press, Tuscaloosa. 357 pp.

Thomas, C. 1861a. The army worm. *Prairie Farmer* 23: 393, 400.

Thomas, C. 1861b. Further from the army worm. *Prairie Farmer* 24: 100.

Thomas, C. 1861c. The army worm. *Illinois Farmer*, September, 1861, pp. 269-273.

Thomas, C. 1861d. The army worm question. *Prairie Farmer* 24: 293.

Thomas, C. 1861e. Army worm question continued. *Prairie Farmer* 24: 306-307.

Walsh, B.D. 1861a. The army worm and its insect foes. *Prairie Farmer* 24: 322-323, 337-339, 354-355.

Walsh, B.D. 1861b. The army worm question – Mr. Walsh's reply. Field Notes 14 Dec.

Walsh, B.D. 1861c. The army worm and its insect foes – the remedy. *Transactions of the Illinois State Agricultural Society* 4: 349-372.

Walsh, B.D. 1861d. The army worm. *Prairie Farmer* 24: 257-258.

Walsh, B.D. 1861e. The army worm question. *Prairie Farmer* 24: 370-371.

Wiley, B. 1861. The army worm. *Prairie Farmer* 24: 37.

# Awesome Aphids – *Aphis glycines* in Michigan in 2001

**CHRISTINA DIFONZO**

In late July 2000, researchers in Wisconsin found aphids feeding on plants in soybean plots. By August, aphids also were discovered on soybean in Illinois, Michigan, and several other midwestern states. Taxonomists finally identified the aphid as a new species to North America: *Aphis glycines* Matsumura, the soybean aphid. *A. glycines* is native to Asia, where the soybean plant itself originated. Its distribution before the 2000 field season included China, Siberian Russia, Japan, Korea, Malaysia, and Thailand. After its discovery in summer 2000, *A. glycines* was found in 40 counties in Michigan, as well as in eight surrounding states. However, by far the heaviest infestations stretched from southern Wisconsin, around Lake Michigan, into southwestern Michigan.

In spring 2001, *A. glycines* was found on the leaves of its overwintering host, *Rhamnus cathartica*, in the Midwest. The aphid rapidly colonized soybean fields across the Lakes States in June. By the end of the year, it was found east into Ontario, northern Ohio, Pennsylvania, and New York, and as far south as Missouri. Researchers from across the region conducted trials to develop a sampling plan for the aphid, and to determine the impact of aphid feeding on soybean yield and quality. This discussion details some of the work done in Michigan in 2001 and gives our recommendation for aphid management in 2002.

# Western Corn Rootworms: Strange Tales in 2001 and Management Options for 2002 (and Beyond)

**KEVIN L. STEFFEY, MICHAEL E. GRAY, AND JOHN T. SHAW**

Rootworm adults collected on the 49th and 50th floors of the Prudential Building in Chicago! "Swarms" of rootworm adults in yards and gardens in metropolitan areas! Children afraid to play outside because of "alarming" numbers of rootworm adults! These phrases sound like headlines from the *National Enquirer* or promotional slogans for very bad horror movies. However, we heard these comments from reliable people who witnessed some of the strangest behavior displayed by western corn rootworms in years. In addition, we received a multitude of "normal" reports of very high densities of western corn rootworm adults in cornfields and extensive damage caused by rootworm larvae. All of this information has raised our level of concern about the potential for rootworm problems in Illinois in 2002. Although predicting rootworm problems is far from an exact science, everyone involved with corn production in Illinois should be on heightened alert next spring and summer.

In this article we provide an overview of corn rootworm activity and some research efforts in 2001 and discuss the options for managing corn rootworms in 2002. Atypical rootworm behavior, the potential spread of the "strain" of western corn rootworms that lay eggs in soybean, and the availability of different types of products (seed treatments, transgenic corn) for rootworm control all figure prominently in the future of rootworm management in Illinois.

## ROOTWORMS IN 2001: HEAVY INFESTATIONS AND BIZARRE BEHAVIOR

Our database associated with rootworms is comprised of both reports of infestations and data gathered from research trials. Reports come to us from agricultural professionals from all regions of Illinois and from entomologists in adjacent states. In addition, our colleagues share results from their rootworm insecticide efficacy trials. All of this information provides a reasonably well-developed picture of rootworm activity during any given year. And developments during any given year provide insight for planning future management strategies. We gained considerable insight in 2001.

### Reports from the Field, and Associated Speculations

Our first inclination that 2001 would be a "rootworm year" occurred in mid-May when heat-unit accumulations in the soil suggested that rootworm larvae would hatch earlier than normal. The weather was warm and dry, so we anticipated good-to-excellent survival of larvae and a potential for poor performance of some rootworm-control products. Larry Bledsoe, an entomologist with Purdue University, found first instars on May 16 in Tippecanoe County, Indiana, the earliest confirmed hatch of corn rootworms in Indiana since 1985.

We received the first report of a heavy infestation of rootworms in mid-June from individuals who had sifted soil and dissected corn roots to look for larvae in a field in western Illinois. By early July, people had begun observing extensive rootworm larval damage in cornfields throughout the northern half of the state. By mid-July, reports of significant rootworm larval damage were relatively common. Several corn producers reported being dissatisfied with the performance of the products they had used for rootworm control. We also learned that rootworm larval damage was severe in the untreated control plots in our rootworm insecticide efficacy trials near DeKalb, Monmouth, and Urbana (Table 1).

We began receiving reports of very large densities of rootworm adults and bizarre rootworm behavior in early August. One individual reported that he had found western corn rootworm adults on the 49th and 50th floors of the Prudential Building in Chicago and that the

numbers exceeded any he had observed in 13 yr. Large numbers of western corn rootworm adults were being washed up on the shores of Lake Michigan, a phenomenon that had occurred at least once before in the late 1980s. Apparently western corn rootworm adults moving from cornfields were caught up in frontal systems and subsequently in downdrafts triggered by atmospheric conditions.

We also began to hear about "hordes" of western corn rootworm adults appearing in suburban and urban gardens, destroying crops of cucurbits and sweet corn. Western corn rootworms are closely associated with both cucurbits and corn, so their proclivity to feed on these crops was not unusual. However, we also received reliable reports of western corn rootworm adults injuring plants on which they usually do not feed: ash trees, black and red raspberries, broccoli, beets, cabbage, marigolds, ornamental cherry trees, redroot pigweed, roses, snap beans, spinach, and velvetleaf, among others. These observations were remarkable because the scientific literature indicates that western corn rootworms have a narrow host range. And the weirdness was not reserved for western corn rootworms. Northern corn rootworms, which have a broader host range than western corn rootworms, were found causing damage in fields of alfalfa in northeastern Illinois. Although finding northern corn rootworm adults in alfalfa is not unusual, extensive feeding on alfalfa is not common.

An explanation for the bizarre behavior of corn rootworms, especially western corn rootworms, in 2001 must be steeped in speculation. However, precedents for changes in behavior of corn rootworms have occurred. In the 1960s, western corn rootworms resistant to chlorinated hydrocarbon insecticides spread across the Corn Belt. The resistant strain of rootworms seemed to be aggressive and dispersed more readily than the nonresistant strain. The resistant strain moved eastward at the rate of approximately 50 mi/yr.

Since the mid-1990s, we have learned that some populations of western corn rootworms lay eggs in crops other than corn in east central, central, and north central Illinois, as well as in northern Indiana, southern Michigan, and western Ohio. In these areas, crop rotation has become ineffective as a rootworm management tactic in many fields. Results from our research indicate that this new strain of western corn rootworm lays eggs in alfalfa, corn, oat stubble, and soybean, and possibly other crops. In essence, their egg-laying behavior has changed (they used to lay eggs solely in corn). We can speculate that this change in egg-laying behavior may be linked to acceptability of a larger range of hosts. Or, maybe densities of western corn rootworm adults were so large in 2001 that they simply "spilled over" into suburban and urban areas and remained because of their affinity for corn and cucurbits. After the rootworm adults consumed the cucurbits and sweet corn, maybe hunger stimulated them to feed on other crops. However, before the change in egg-laying behavior occurred, western corn rootworm adults did not feed on soybean foliage. Now, western corn rootworm adults feed readily on soybean leaves.

The relatively recent history of corn rootworms in North America is rife with examples of their ability to adapt. Western corn rootworms have become resistant to chlorinated hydrocarbon insecticides and some organophosphate and carbamate insecticides, and they have adapted to crop rotation by changing their egg-laying behavior. Northern corn rootworms have adapted to crop rotation in the western Corn Belt by undergoing extended diapause. Therefore, we should not be surprised if the rootworms' bizarre behavior in 2001 becomes another recognized adaptation to their environment. Regardless of the reasons for these changes in behavior, management of corn rootworms will remain a challenge for a long time.

## Results from Rootworm Insecticide Efficacy Trials in 2001

Every year, entomologists throughout the Corn Belt conduct research trials to determine the efficacy of registered and experimental products for control of corn rootworms. Corn growers and agricultural input suppliers are particularly interested in the efficacy of new products for control of corn rootworms compared with the efficacy of granular soil insecticides that are used most commonly. The advent of some liquid insecticides and seed treatments for rootworm control has generated significant interest.

Herein we report the results of efficacy trials conducted by us and by entomologists at Purdue University and Iowa State University. We believe that results from several locations provide a more comprehensive representation of product performance.

*Illinois.* We establish three trials annually on University of Illinois research farms near DeKalb, Monmouth, and Urbana. In 2001, we evaluated the efficacy of granular soil insecticides, liquid insecticides, and seed treatments. The primary evaluation for these trials was an assessment of root damage caused by corn rootworm larvae. We used the 1-6 root-rating scale established at Iowa State University (Hills and Peters, 1971):

1. No visible damage or only a few minor feeding scars
2. Some roots with feeding scars, but none eaten off to within 1.5 inches of the plant

**Table 1. Mean root ratings for corn rootworm-control products at three locations in Illinois, 2001.**

| Treatment | Rate[1] | Placement | Root ratings[2,3] DeKalb | | Monmouth | | Urbana | |
|---|---|---|---|---|---|---|---|---|
| Capture 2EC | 0.082 | Band | 3.3 | c–f | 3.6 | b–h | 3.4 | d–h |
| Capture 2EC | 0.082 | Furrow | 3.6 | c–f | 3.6 | b–g | 3.3 | d–h |
| Capture 1.15G | 0.100 | Furrow | 3.5 | c–f | 3.3 | d–i | 3.7 | c–f |
| Capture 1.15G | 0.100 | Band | 3.4 | c–f | 4.3 | bcd | 3.5 | d–g |
| Force 3G | 0.130 | Band | 2.9 | ef | 3.0 | f–j | 2.9 | e–h |
| Counter CR | 1.300 | Band | 3.9 | cde | 2.3 | j | 2.2 | h |
| Aztec 4.67G | 0.150 | Band, Smartbox | 3.0 | ef | 2.6 | hij | 2.5 | fgh |
| Aztec 4.67G | 0.150 | Furrow, Smartbox | 2.8 | f | 2.3 | j | 3.0 | e–h |
| Aztec 2.1G | 0.153 | Band | 3.3 | def | 2.7 | f–j | 2.4 | gh |
| Aztec 2.1G | 0.153 | Furrow | 3.4 | c–f | 2.7 | ij | 2.4 | gh |
| Fortress 5G | 0.160 | Furrow, Smartbox | 4.4 | abc | 4.5 | b | 2.9 | e–h |
| Fortress 5G | 0.160 | Band, Smartbox | 4.0 | cde | 4.3 | bc | 2.9 | e–h |
| ProShield | 1.200 | Seed treatment | 3.6 | d–f | 3.0 | e–j | 3.9 | b–e |
| Prescribe | 1.340 | Seed treatment | 3.6 | c–f | 3.7 | b–f | 4.5 | a–d |
| Lorsban 15G | 1.300 | Band | 4.0 | cde | 2.7 | f–j | 2.4 | gh |
| Regent 4SC | 0.130 | Microtube | 4.0 | cde | 3.4 | c–i | 3.7 | c–f |
| Clothianidin | 1.250 | Seed treatment | 3.6 | c–f | 3.6 | b–g | 3.7 | c–g |
| Nufos 15G | 1.300 | Band | 3.4 | c–f | 2.7 | g–j | 2.8 | e–h |
| Furadan 4F | 1.000 | Broadcast | — | | — | | 4.8 | abc |
| Untreated control | | | 5.2 | a | 5.4 | a | 5.5 | a |

[1] Rates are expressed as pounds of active ingredient per acre (lb a.i./acre), except for seed treatments, which are expressed as milligrams per seed.
[2] Root ratings based on the 1–6 root-rating scale (Hills and Peters, 1971).
[3] Means in a column followed by the same letter are not significantly different ($P > 0.05$; Duncan's New Multiple Range test).

3. Several roots eaten off to within 1.5 inches of the plant, but never the equivalent of an entire node of roots destroyed
4. One node of roots destroyed, or the equivalent
5. Two nodes of roots destroyed, or the equivalent
6. Three or more nodes of roots destroyed

Many people consider that a root rating of 3.0 or higher indicates the potential for economic yield loss. Most people also realize that yield loss is probable if the root rating reaches or exceeds 4.0, which represents significant root pruning. However, the amount of root damage required to cause yield loss depends upon the interaction of the hybrid grown and environmental conditions (Gray and Steffey, 1998).

The amount of rootworm larval damage was severe in the untreated control plots at all three sites: mean root ratings of 5.2, 5.4, and 5.5 at DeKalb, Monmouth, and Urbana, respectively (Table 1). However, environmental conditions at the three sites were different, and the results reflect these differences. In the discussion that follows, plots to which rootworm-control products were applied are referred to as treated plots.

In DeKalb, most treated plots had mean root ratings of 3.0 or greater (Table 1). Only plots treated with Force 3G in a band and Aztec 4.67G in furrow had mean root ratings less than 3.0. However, except for the plots treated with Fortress 5G in furrow, the mean root ratings in treated plots were significantly lower than the mean root rating in the untreated control. Consistency of most products was less than 75% (Table 2.) The DeKalb site received very little rainfall during June and July, so we surmise that the lack of soil moisture may have been responsible for less-than-satisfactory performance of most rootworm-control products.

The Monmouth site received more rainfall than the DeKalb site, so more treated plots had mean root ratings less than 3.0 (Table 1): Counter CR in a band (2.3), Aztec 4.67G in a band (2.6) and in furrow (2.3), Aztec 2.1G in a band (2.7) and in furrow (2.7), Lorsban 15G in a band (2.7), and Nufos 15G (active ingredient, chlorpyrifos, the

same as in Lorsban 15G) in a band (2.7). The mean root ratings in all treated plots were significantly lower than the mean root rating in the untreated control. Mean root ratings in plots treated with Capture 1.15G in a band and Fortress 5G in furrow and in a band were greater than 4.0. Consistency of the following products was 90% or greater (Table 2): Counter CR (95%), Aztec 4.67G in a band and in furrow (both 100%), Aztec 2.1G in a band (100%) and in furrow (95%), Lorsban 15G (90%), and Nufos 15G (90%).

At the Urbana site, plots treated with the following products had mean root ratings less than 3.0 (Table 1): Force 3G in a band (2.9), Counter CR in a band (2.2), Aztec 4.67G in a band (2.5), Aztec 2.1G in a band and in furrow (both 2.4), Fortress 5G in furrow and in a band (both 2.9), Lorsban 15G in a band (2.4), and Nufos 15G in a band (2.8). Mean root ratings in all except the following treated plots were significantly lower than the mean root rating in the untreated control: Prescribe seed treatment (4.5) and Furadan 4F broadcast (4.8). Consistency of the following products was 90% or greater (Table 2): Counter CR in a band (98%), Aztec 4.67G in a band (93%), Aztec 2.1G in a band and in furrow (both 100%), and Nufos 15G in a band (90%).

**Table 2. Mean percentage of consistency for corn rootworm-control products at three locations in Illinois, 2001.**

| Treatment | Rate[1] | Placement | % Consistency[2,3] DeKalb | Monmouth | Urbana |
|---|---|---|---|---|---|
| Capture 2EC | 0.082 | Band | 55 | 55 | 55 |
| Capture 2EC | 0.082 | Furrow | 47 | 55 | 70 |
| Capture 1.15G | 0.100 | Furrow | 60 | 60 | 60 |
| Capture 1.15G | 0.100 | Band | 50 | 20 | 60 |
| Force 3G | 0.130 | Band | 87 | 75 | 87 |
| Counter CR | 1.300 | Band | 33 | 95 | 98 |
| Aztec 4.67G | 0.150 | Band, Smartbox | 85 | 100 | 93 |
| Aztec 4.67G | 0.150 | Furrow, Smartbox | 80 | 100 | 80 |
| Aztec 2.1G | 0.153 | Band | 60 | 100 | 100 |
| Aztec 2.1G | 0.153 | Furrow | 75 | 95 | 100 |
| Fortress 5G | 0.160 | Furrow, Smartbox | 25 | 15 | 85 |
| Fortress 5G | 0.160 | Band, Smartbox | 45 | 20 | 80 |
| ProShield | 1.200 | Seed treatment | 50 | 80 | 55 |
| Prescribe | 1.340 | Seed treatment | 50 | 35 | 20 |
| Lorsban 15G | 1.300 | Band | 25 | 90 | 75 |
| Regent 4SC | 0.130 | Microtube | 30 | 45 | 50 |
| Clothianidin | 1.250 | Seed treat | 35 | 50 | 55 |
| Nufos 15G | 1.300 | Band | 53 | 90 | 90 |
| Furadan 4F | 1.000 | Broadcast | — | — | 15 |
| Untreated control | | | 0 | 5 | 0 |

[1] Rates are expressed as pounds of active ingredient per acre (lb a.i./acre), except for seed treatments, which are expressed as milligrams per seed.

[2] Percentage of consistency is the percentage of the total number of roots examined with a root rating less than 4.0.

[3] Means in a column followed by the same letter are not significantly different ($P > 0.05$; Duncan's New Multiple Range test).

The liquid insecticides evaluated at all three locations were Capture 2EC and Regent 4SC. Furadan 4F was evaluated only at Urbana. The mean root ratings in all plots treated with liquid insecticides were greater than 3.0 (Table 1). However, mean root ratings in plots treated with Capture and Regent were significantly lower than mean root ratings in the untreated controls. The consistency of liquid insecticides was 70% or less at all three locations (Table 2).

Seed treatments evaluated at all three locations were ProShield, Prescribe, and clothianidin (common name; not registered yet). The mean root ratings in all plots with seed treatments were 3.0 or greater (Table 1). However, except for Prescribe at Urbana (mean root rating of 4.5), mean root ratings in all plots with seed treatments were significantly lower than mean ratings in the untreated controls.

*Indiana*. Larry Bledsoe, an entomologist at Purdue University, established corn rootworm insecticide efficacy trials near Lafayette, Farmland, and Columbia City, IN, in 2001. The mean root rating in the untreated control at Columbia City was less than 3.0, so data from that site are not discussed. The primary evaluation for these trials was an assessment of root damage caused by corn rootworm larvae. Larry used the 1-6 root-rating scale established at Iowa State University (Hills and Peters, 1971).

The mean root ratings in the untreated controls at Lafayette (4.6) and Farmland (4.65) indicated a moderately high level of rootworm larval damage (Table 3). With only a few exceptions, mean root ratings in treated plots were less than 3.0 in both locations (Table 3). At the Lafayette site, mean root ratings in the following

**Table 3. Mean root ratings for corn rootworm-control products at three locations in Indiana, 2001. (Data provided by Larry Bledsoe, Department of Entomology, Purdue University, West Lafayette, IN.)**

| Treatment | Rate[1] | Placement | Root ratings[2,3] | | |
|---|---|---|---|---|---|
| | | | Lafayette | Farmland | Columbia City |
| Counter CR | 1.20 | Band | 2.90 | 1.45 | 1.35 |
| Counter CR | 1.20 | Furrow | 3.40 | 1.60 | 1.75 |
| Lorsban 15G | 1.20 | Band | 3.60 | 1.70 | 1.40 |
| Lorsban 15G | 1.20 | Furrow | 3.00 | 2.05 | 1.70 |
| Force 3G | 0.12 | Band | 2.00 | 2.00 | 1.75 |
| Force 3G | 0.12 | Furrow | 2.15 | 2.05 | 1.70 |
| Aztec 2.1G | 0.14 | Band | 2.05 | 2.00 | 1.35 |
| Aztec 2.1G | 0.14 | Furrow | 2.13 | 1.80 | 1.55 |
| Aztec 4.67G | 0.14 | Band, Smartbox | 2.05 | 1.50 | 1.25 |
| Aztec 4.67G | 0.14 | Furrow, Smartbox | 2.05 | 1.90 | 1.30 |
| Warrior T | 0.03 (lb a.i./acre) | Band | 3.65 | 3.55 | 2.00 |
| Fortress 5G | 0.15 | Band, Smartbox | 2.85 | 1.70 | 1.60 |
| Fortress 5G | 0.15 | Furrow, Smartbox | 2.80 | 1.80 | 1.60 |
| Regent 4SC | 0.13 (lb a.i./acre) | Microtube | 2.85 | 2.70 | 1.55 |
| Capture 1.15G | 0.092 | Band | 2.45 | 2.55 | 2.00 |
| Capture 1.15G | 0.092 | Furrow | 2.80 | 2.80 | 1.65 |
| Capture 2EC | 0.082 (lb a.i./acre) | Band | 2.65 | 2.40 | 1.90 |
| Capture 2EC | 0.082 (lb a.i./acre) | Furrow | 2.30 | 2.65 | 1.70 |
| ProShield | 1.20 | Seed treatment | 2.60 | 2.15 | 1.60 |
| Prescribe | 1.34 | Seed treatment | 2.55 | 2.15 | 1.35 |
| Clothianidin | 1.23 | Seed treatment | 2.45 | 1.85 | 1.70 |
| Clothianidin | 0.25 | Seed treatment | 2.85 | 2.60 | 1.90 |
| Adage/Cruiser | 50 g/100 kg of seed | Seed treatment | 4.00 | 3.55 | 2.20 |
| Untreated control | | | 4.60 | 4.65 | 2.75 |

[1] Rates are expressed as ounces of active ingredient per 1,000 feet of row (oz a.i./1,000 ft), unless noted otherwise. Rates for seed treatments are expressed as milligrams per seed, unless noted otherwise.
[2] Root ratings based on the 1–6 root-rating scale (Hills and Peters, 1971).
[3] Mean root ratings have not been analyzed statistically.

treated plots were 3.0 or greater: Counter CR in furrow (3.4), Lorsban 15G in a band (3.6) and in furrow (3.0), Warrior T (3.65), and Adage/Cruiser seed treatment (4.0). At the Farmland site, mean root ratings in the following treated plots were 3.0 or greater: Warrior T (3.55) and Adage/Cruiser seed treatment (3.55).

Capture 2EC was the only liquid insecticide evaluated at both the Lafayette and Farmland sites. The seed treatments ProShield, Prescribe, Clothianidin, and Adage/Cruiser also were evaluated at both sites. Except for the seed treatment Adage/Cruiser, all of these products provided acceptable rootworm control (mean root rating less than 3.0).

*Iowa.* Jim Oleson, the insecticide efficacy program coordinator in the Department of Entomology at Iowa State University, established corn rootworm insecticide efficacy trials at five locations in Iowa in 2001. He provided the data as averages over all five sites. The primary evaluation for these trials was an assessment of root damage caused by corn rootworm larvae. Jim used the 0-3 node-injury scale, also established at Iowa State University. The node-injury scale describes the degree of root pruning more precisely than the 1-6 root-rating scale described previously. The node-injury scale includes both the number of nodes of roots completely destroyed (0 to 3, the number to the left of the decimal) and the percentage of a node eaten (0.01 to 0.99, the number to the right of the decimal).

The node-injury rating averaged the untreated controls in the five trials in Iowa in 2001 was 1.78 (Table 4), equivalent to a root rating of slightly less than 5.0 on the 1-6 root-rating scale, indicating a moderately high level of rootworm larval damage. The mean node-injury ratings in all treated plots were significantly lower than the mean

node-injury rating in the untreated control plot (Table 4). The mean node-injury ratings in the following treated plots were 1.0 or greater: ProShield seed treatment (1.05), Regent 4SC in furrow (1.07), and Prescribe seed treatment (1.18). The average consistency of all products in Iowa in 2001 was less than 60% (Table 4), possibly attributable to greater-than-expected survival of rootworm larvae, weather conditions, and late planting (7–10 days later than normal). The consistency of the following products was not significantly different from the consistency in the untreated control: Lorsban 15G in a band (40%) and in furrow (27%), Fortress 5G in a band (39%), Capture 2EC in a band (33%) and in furrow (28%), ProShield seed treatment (27%), Regent 4SC in furrow (28%), and Prescribe seed treatment (16%).

Table 5 shows the mean node-injury ratings and percentage of consistency for several products evaluated in Iowa over the past 4 yr (1998–2001). For each product, the mean node-injury rating was significantly lower and mean percentage of consistency was significantly greater than respective evaluations in the untreated control. Mean node-injury ratings in all treated plots were less than 1.0, indicating less than an average of one node of roots destroyed. The consistency of only three products was greater than 75%: Force 3G in furrow (82%) and Aztec 2.1G in furrow (80%) and in a band (78%).

**Table 4. Mean node-injury ratings[1] and percentage of consistency for corn rootworm-control products in Iowa, 2001. (Data were provided by Jim Oleson, Department of Entomology, Iowa State University, Ames, IA.)**

| Treatment[2] | Placement | Node-injury rating[3,4] | | % Consistency[4,5] | |
|---|---|---|---|---|---|
| Aztec 4.67G | Furrow, Smartbox | 0.42 | a | 58 | a |
| Counter CR | Furrow | 0.44 | a | 59 | a |
| Aztec 2.1G | Band | 0.45 | a | 52 | abc |
| Aztec 2.1G | Furrow | 0.46 | ab | 54 | ab |
| Force 3G | Furrow | 0.49 | abc | 52 | abc |
| Fortress 5G | Furrow, Smartbox | 0.52 | abc | 58 | a |
| Counter CR | Band | 0.55 | abc | 50 | abc |
| Aztec 4.67G | Band, Smartbox | 0.57 | abc | 45 | abc |
| Lorsban 15G | Band | 0.66 | abc | 40 | a–d |
| Force 3G | Band | 0.67 | abc | 42 | abc |
| Fortress 5G | Band, Smartbox | 0.68 | a–d | 39 | a–d |
| Lorsban 15G | Furrow | 0.81 | a–e | 27 | cd |
| Capture 2EC | Band | 0.85 | b–e | 33 | bcd |
| Capture 2EC | Furrow | 0.88 | cde | 28 | cd |
| ProShield | Seed treatment | 1.05 | de | 27 | cd |
| Regent 4SC | Furrow, microtube | 1.07 | e | 28 | cd |
| Prescribe | Seed treatment | 1.18 | e | 16 | d |
| Untreated control | | 1.78 | f | 6 | d |

[1] Means from 24 replications at five different locations. Means for treatments are based upon 120 observations; the mean for the untreated control is based upon 170 observations. Replications that did not have sufficient larval feeding to challenge a product's performance (untreated check replication mean <0.75) were deleted from analyses.

[2] Rates of application not provided.

[3] Iowa State University 0–3 node-injury scale. The number to the left of the decimal indicates the number of nodes completely destroyed. The number to the right of the decimal indicates the percentage of a node eaten. (For example, a node-injury rating of 1.78 means that one node was completely destroyed and 78% of another node was eaten.)

[4] Means in a column followed by the same letter do not differ significantly according to Ryan's Q test ($P > 0.05$).

[5] Percentage of consistency is the percentage of the total number of roots examined with a node-injury rating of 0.25 or less.

## MANAGEMENT OF CORN ROOTWORMS IN 2002 (AND BEYOND)

### Anticipating Changes in Management of Corn Rootworms

Although the insecticide products have changed, strategies for managing corn rootworms have not changed much during the past few decades. Since the 1950s, corn growers have relied primarily on the use of soil insecticides and crop rotation to manage corn rootworms. In some areas of the Corn Belt, application of insecticides to prevent corn rootworms from laying eggs has been routine since the 1970s. However, we now find ourselves at a threshold of significant changes in the tools and strategies we use to manage corn rootworms. These significant changes have been induced by a succession of critical events in the relatively short time we have had to protect our corn from corn rootworms:

- Western corn rootworms became resistant to the chlorinated hydrocarbon insecticides.
- Western corn rootworms spread eastward rapidly from western states throughout the Midwest and into eastern states.
- Some northern corn rootworm populations in the western Corn Belt became capable of extended diapause, thereby overcoming crop rotation as a management tactic.
- Some western corn rootworm populations in the eastern Corn Belt began laying eggs in crops other than

**Table 5. Four-year (1998–2001) summary[1] of node-injury ratings and percentage of consistency for corn rootworm insecticides in Iowa. (Data were provided by Jim Oleson, Department of Entomology, Iowa State University, Ames, IA.)**

| Treatment[2] | Placement | Node-injury rating[3,4] | | % Consistency[4,5] | |
|---|---|---|---|---|---|
| Force 3G | Furrow | 0.22 | a | 82 | a |
| Aztec 2.1G | Furrow | 0.23 | a | 80 | a |
| Aztec 2.1G | Band | 0.23 | a | 78 | a |
| Force 3G | Band | 0.30 | ab | 73 | ab |
| Counter CR | Furrow | 0.33 | ab | 72 | ab |
| Counter CR | Band | 0.34 | ab | 72 | ab |
| Fortress 5G | Furrow, Smartbox | 0.39 | ab | 69 | ab |
| Lorsban 15G | Band | 0.47 | bc | 62 | b |
| Fortress 5G | Band, Smartbox | 0.47 | bc | 61 | b |
| Lorsban 15G | Furrow | 0.60 | cd | 50 | c |
| Regent 4SC | Furrow, microtube | 0.72 | d | 49 | c |
| Untreated control | | 1.73 | e | 9 | d |

[1] Means from 93 replications. Means of treatments are based upon 372 observations; means from untreated control were based upon 764 observations. Replications that did not have sufficient larval feeding to challenge a product's performance (untreated check replication mean <0.75) were deleted from analyses.

[2] Rates of application not provided.

[3] Iowa State University node-injury scale 0–3. The number to the left of the decimal indicates the number of nodes completely destroyed. The number to the right of the decimal indicates the percentage of a node eaten. (For example, a node-injury rating of 1.78 means that one node was completely destroyed and 78% of another node was eaten.)

[4] Means in a column followed by the same letter do not differ significantly according to Ryan's Q test ($P > 0.05$).

[5] Percentage of consistency is the percentage of the total number of roots examined with node-injury rating of 0.25 or less.

corn, thereby overcoming crop rotation as a management tactic.

- Western corn rootworms became resistant to carbaryl (active ingredient in Sevin) and methyl parathion (active ingredient in Penncap-M), two products used extensively in Nebraska to prevent rootworm from laying eggs.
- FQPA has affected a critical review of pesticides, resulting in significant changes in labeling, including cancellations, of many insecticides.

Although the primary tactics for controlling corn rootworms still are the use of granular soil insecticides and crop rotation, changes are underway. Insecticidal seed treatments and liquid insecticides are challenging granular soil insecticides for market share. Agricultural companies are investigating new ways of delivering insecticides to corn rootworm larvae. Scouting for western corn rootworm adults in soybean has become commonplace in parts of Illinois, Indiana, Michigan, and Ohio. And the prospect of planting transgenic *Bacillus thuringiensis* (Bt) corn hybrids for rootworm control has provoked intense examination of both our current and future management strategies, renewing interest in rootworm population research.

## Managing Corn Rootworms in 2002 and in the Near Future

Regardless of the pending changes, developing a rootworm management plan with the tools currently available and with up-to-date knowledge is essential. A management plan for corn rootworms should be long range (not a year at a time) and include crop rotation, judicious use of insecticides, and scouting to determine the need for rootworm control. We cannot emphasize scouting enough. The only way to determine whether an insecticide is needed to protect the corn crop is to scout for adults in either corn or soybean and compare the numbers observed with established economic thresholds.

Consider the following points to develop a long-range rootworm management program:

- Scout for rootworm adults in corn from mid-July through early September to determine the potential for rootworm larval damage the following year.
- Alternate corn with another crop when possible, particularly in fields where the average number of rootworm adults in corn is 0.75 or more per plant
- If the plan is to grow corn after corn and if the average number of rootworm adults is 0.75 or more per plant in corn after corn or 0.5 per plant in first-year corn, apply a rootworm-control product at planting time. Refer to the data presented in Tables 1-4 to review efficacy data from 2001.
  - Granular soil insecticides registered for control of corn rootworm larvae are Aztec 2.1G and 4.67G (through Smartbox only), Counter CR, Force 3G, Fortress 5G (through Smartbox only), Lorsban 15G, and Thimet 20G.
  - Liquid soil insecticides registered for control of corn rootworm larvae are Capture 2EC, Furadan 4F (we recommend at cultivation only), Lorsban 4E

(we recommend at cultivation only), and Regent 4SC.

- Two insecticidal seed treatments are labeled for control of corn rootworm larvae. ProShield technology with Force ST insecticide is available on some NK brand hybrids, marketed by Novartis Seeds. Prescribe (imidacloprid is the active ingredient) is marketed by Gustafson and is available on hybrids sold by several seed companies. Both products are applied to the corn seeds by seed suppliers before the seeds are bagged.
  These seed treatments have been evaluated in efficacy trials for three or more years at the University of Illinois and at other land-grant universities in the Midwest. In general, when rootworm densities have not been high and root injury has been slight to moderate, both seed treatments have provided acceptable protection of the roots. However, when rootworm densities have been high and root injury has been severe, neither of these insecticidal seed treatments has provided consistently acceptable control of corn rootworm larvae. Therefore, we do not recommend their use in fields where the risk of rootworm larval damage is significant.

- Another alternative for corn after corn is controlling rootworm adults in corn to prevent them from laying eggs. If the number of adults reaches or exceeds 0.75 per plant, apply an insecticide when 10% of the females are gravid (with eggs). Continue to monitor fields weekly after treatment for rootworm adults. A second application of an insecticide may be necessary if the number of adults reaches or exceeds 0.5 per plant.

- Producers may encounter rootworm larval damage in corn planted after soybean in the following Illinois counties: Champaign, Christian, Coles, DeKalb, DeWitt, Douglas, Edgar, Ford, Grundy, Iroquois, Kane, Kankakee, Kendall, LaSalle, Lee, Livingston, Logan, Macon, Marshall, McLean, Moultrie, Ogle, Peoria, Piatt, Putnam, Sangamon, Shelby, Tazewell, Vermilion, Warren, Will, and Woodford. However, the occurrence of western corn rootworm adults that lay eggs in soybean fields is not restricted by county lines. Therefore, growers in counties adjacent to the aforementioned counties should remain observant for the occurrence of the problem in their fields.

- Producers who have experienced rootworm larval injury in first-year corn and have found western corn rootworm adults in adjacent soybean fields should consider using a rootworm-control product in corn rotated with soybean. An economic threshold for adult western corn rootworms in soybean has been developed to help producers determine whether a rootworm-control product is needed to protect corn the next year. People can sample for western corn rootworm adults by placing 12 unbaited Pherocon AM traps (yellow sticky traps) systematically throughout the interior of a soybean field. If the number of western corn rootworm adults from the last week of July through the 3rd wk of August exceeds an average of five beetles per trap per day, corn rootworm larvae may cause economic damage to corn roots the next year.

- Growers outside of the affected area are encouraged not to use a rootworm-control product on first-year corn. As of 2001, the new "strain" of western corn rootworm had not been detected in counties other than the 32 mentioned previously.

Transgenic corn hybrids resistant to corn rootworms are being developed and could be commercially available soon. Stewardship of these transgenic hybrids will require appropriate use and implementation of resistance management plans. However, scientists still do not agree on how the resistance management strategies should be deployed. Nevertheless, the eventual commercialization of transgenic rootworm-resistant hybrids will ring in a new era for rootworm management. It's up to us to make certain that we learn from our past mistakes to avoid repeating them.

## REFERENCES


Gray, M.E., and K.L. Steffey. 1998. Corn rootworm (Coleoptera: Chrysomelidae) larval injury and root compensation of 12 maize hybrids: an assessment of the economic injury index. *Journal of Economic Entomology* 91: 723-740.

Hills, T.M., and D.C. Peters. 1971. A method of evaluating post-plant insecticide treatments for control of western corn rootworm larvae. *Journal of Economic Entomology* 64: 764-765.

# White Grubs: A Tale of Three Rasters

LARRY W. BLEDSOE

Crop injury by white grubs appears to be increasing in the eastern Corn/Soybean Belt. This perception of increased injury may be due to greater overall prevalence of one or more of these insect species, or simply to an increasing awareness of this group of pests. Historical weather data suggest that fall and winter soil temperatures have been warming during the last several decades. Could increasing soil temperatures be contributing to the rise in white grub injury reports? The reduction in tillage in the last decade has resulted in the trend toward earlier planting, which puts seeds and seedlings in harm's way for extended periods. Crop rotation is used in many areas to manage the corn rootworm without insecticides. Does this practice allow damage from other pests such as white grubs to build up? Or, does it just seem like white grub injury is more prevalent now because of effective crop management education programs that raises awareness of potential insect problems among farmers, crop consultants, and farm managers? Does the regionally cyclic nature of some white grub populations make us think that numbers are increasing because there always seems to be a problem somewhere? Also, is the chemical industry emphasizing these pests in an effort to expand markets? The economic impact of these insects is poorly understood because their direct damage is underground, the infestations tend to be transient and local, and crop losses can be variably affected by a previous crop, planting date, seed selection, soil type, weather, and white grub species. Incomplete knowledge of these pests and their injury results in ambiguous and often erroneous crop loss information; thus, much more effort must be expended before their true economic impact is clear. An understanding of the white grub species found in eastern Midwest cropland and their potential to injure crops is essential in determining their importance as crop pests.

White grubs are the larvae of several species of scarab beetles that occasionally injure turf and field crops.

Injurious species commonly found in the eastern Corn/Soybean Belt include the Japanese beetle (*Popillia japonica*); the annual white grubs (*Cyclocephala* spp.), known as masked chafers; and the true white grubs (*Phyllophaga* spp.), known as May or June beetles. Although grape colaspis larvae are white and grublike, they are not included in the white grub family. The varying life histories and injury potentials of the different species of white grubs must be considered before appropriate management options can be formulated.

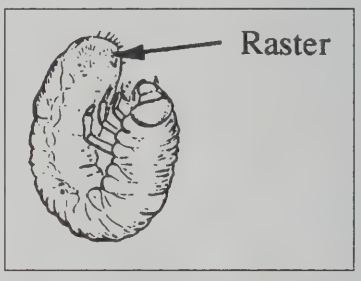



**Figure 1. White raster location.**

Proper identification of the three white grub groups is essential and fortunately very easy. Raster patterns are the unique arrangement of small hairs and spines on the underside of the last (tail) segment of the grub (Figure 1). The patterns can often be seen with the unaided eye on

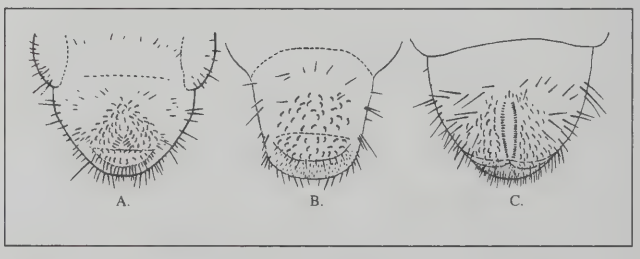



**Figure 2. White grub raster patterns. (A) Japanese beetle. (B) Masked chafer. (C) May or June beetle.**

Figures 1 and 2 were modified from the *Corn and Soybean Field Guide*. 2000. Purdue Crop Diagnostic Training and Research Center and the Purdue Pest Management Program. Publication ID-179, page 42. Purdue University Cooperative Extension Service. West Lafayette, IN.

large larvae; however, a 10× hand lens is needed when examining the smaller larvae.

The Japanese beetle raster (Figure 2A) has an arrangement of hairs forming overlapping V-shaped patterns. These lines of hairs form a "V" that is usually distinct in the center of the pattern. This pest has a 1-yr life cycle. Larvae hatch from eggs laid in mid- to late summer and they feed through the fall until winter drives them deep into the soil. In early spring, the larvae move near the soil surface and briefly resume feeding until they change from the immature stage to the adult, beginning in late spring. Adult beetles emerge from the soil in early summer. Japanese beetle adults feed on corn and soybean foliage and occasionally females lay eggs in sufficient numbers to cause larval damage to seeds and seedlings planted the following year. Very early planted corn is most vulnerable to damage. Japanese beetle larvae feed on soybean roots but rarely cause significant losses. Recent reports suggest that increased damage may occur when soybean is planted unusually early and the seeds are slow to germinate or grow for several weeks. Although soils with very high percentages of sand or organic matter tend to be more consistently infested, crops planted in infested areas with low organic matter tend to be injured most often. This trend may be because Japanese beetle larvae glean decaying organic matter from the soil for food, and where organic matter is limited, larvae feed more often on living plant roots.

The northern and southern masked chafers have a random pattern of hairs on their rasters. The overall pattern of hairs appears oval with no other distinct feature (Figure 2B). The last body segment is tapered instead of rounded. These white grubs have an annual life cycle very similar to that of the Japanese beetle. Adult masked chafers do not feed, and therefore are not a threat to corn or soybean foliage. The larvae can seriously injure grass roots but rarely cause economic injury to either corn or soybean. It is very important to correctly identify this insect to prevent unnecessary insecticide applications.

The true white grub has a raster pattern that has hairs in the center arranged in nearly parallel rows (Figure 2C), resembling an open zipper. This grub has a 3-yr life cycle in the Midwest. Eggs are laid in mid- to late summer, and larvae hatch and molt once before winter dormancy. The grubs move near the soil surface in the spring and feed on many types of plant roots, including corn and soybean throughout the second summer. The grubs molt twice and enter fall dormancy as third instars before reemerging in the spring of the third year. Mature larvae feed until they change into adults by midsummer. Localized broods can form so that large numbers of adult beetles can be predicted 1 or 2 yr in advance. The true white grub is the most potentially damaging white grub species in field crops in the eastern Midwest. Fortunately, economic infestations are not common in this region and are usually restricted to field edges, especially where willows occur.

# Labels, Science, and Reality

FRED WHITFORD

## CONCERNS

Health issues are the subject of lively public debate concerning pesticide use. We are exposed to pesticides in the food and water we consume and in the air we breathe; we're exposed at home, at work, and at play. Thus, questions arise as to how much risk pesticides pose. The general public and government policymakers want clear, definitive answers; and answers to questions on the relationship of pesticides and public health are based largely on information generated through risk assessment.

### Initial Focus on Dietary Risks

Nearly all Americans are exposed to some level of pesticides in their diet. Thus, understanding the risk potential of pesticide residues in food is critical not only for consumers but also for producers, food processors, pesticide manufacturers, and government agencies; their efforts must interlink to ensure a healthful food supply. Various health organizations, government agencies, and academic institutions first began evaluating the risk potential of pesticide residues in food and water in the 1940s. These early risk assessments were conducted in part because of increased surveillance by state, federal, and international governments.

### Attention Shifts to Occupational Risks

Risk assessors in the 1950s began to question the risk posed to workers handling concentrated pesticide products (e.g., pesticide applicators) and to field-workers exposed to residues on foliage (e.g., workers picking apples). This focus on worker exposure was driven by physicians' and industrial hygienists' attempts to determine how workers became overexposed and therefore ill. The advent of occupational risk assessment necessitated new methods for calculating risk—avenues previously unexplored in dietary risk assessment. Exposure from various routes at varying frequency and duration had to be considered.

### Public Scrutiny over Residential Risks

Risk assessors in the late 1980s began to focus on risks from pesticides used in and around the home and workplace. Previously, risk assessors and risk managers had thought that demonstration of minimal risk to applicators and field-workers provided (by default) adequate safeguards for residential use of a given pesticide because the potential for pesticide exposure is many times lower with residential use than with occupational use; but in recent years this assumption has been questioned.

Some suggest that occupational risk assessment conducted for pesticide handlers and field-workers may not reflect risk to the young, the elderly, the sick, or other frail segments of society. Their argument is that safety standards for occupational settings are calculated for healthy workers, typically males aged 20–50. So the assumptions made, information used, and conclusions drawn via the occupational risk assessment process may not pertain to those who may be more sensitive to pesticides—children, the elderly, the sick—or to those who experience high levels of exposure.

## THE SCIENCE

The risk of pesticide exposure to human health is a function of both exposure and toxicity. Because both measurements involve a degree of uncertainty, risk assessments generally use very conservative assumptions to ensure adequate margins of safety. The risk assessment process generally proceeds in a tiered manner from assessments based on very limited data with very conser-

vative assumptions through assessments with extensive data and a solid understanding of the pesticide and its human exposure effects. The tiered approach allows for low-risk pesticides with large margins of exposure to be screened out of the risk assessment process at a very early stage; this approach facilitates the direction of resources to assessment of risk posed by those pesticides of greatest concern to human health.

State-of-the-art risk assessment methodologies are used to assess exposure and risk to special subpopulations. Therefore, risks to infants and children and to workers are evaluated separately from those posed to human populations in general. Risk assessments are increasingly concerned with the aggregate risk of pesticide exposure to humans where the combination of risk from multiple sources (air, food, water, playground, home) is considered.

## THE LABEL

Accompanying each pesticide product is a label that provides written instructions for achieving the desired level of pest management–the *benefits*. The label also provides detailed statements communicating the risks and standards of care associated with the use of the product–the *liabilities*. The instructions and precautions become a legal benchmark by which the actions of the user are compared with the expected "standards of conduct" outlined by the label.

It is the label that establishes a standard of care. The label statement, *It is a violation of federal law to use this product inconsistent with its labeling*, obligates the user to follow product stewardship instructions. This label statement legally binds the user to follow label directions because Federal Insecticide, Fungicide, and Rodenticide Act and state pesticide laws mandate that actions contrary to label directions are considered unlawful acts.

The words *use*, *inconsistent*, and *labeling* need further explanation in the sentence *It is a violation of federal law to use this product in a manner inconsistent with its labeling*. The pesticide label and additional written materials that accompany a product collectively comprise the pesticide *labeling*. Labeling also includes additional sources of information (e.g., Environmental Protection Agency [EPA] Worker Protection Standard, EPA Endangered Species Program Bulletin, state Ground Water Management Plan, company Product Use Bulletins) referenced on the label or accompanying materials.

The word *use* carries the usual connotation of pesticide application, but its legal definition is intended to include handling, mixing, loading, storage, transportation, and disposal. This all-encompassing definition covers every activity that involves a pesticide–from product purchase to container disposal.

## THE REALITY

Despite the public desire for zero risk, the world is not risk free. Recognition of the risks associated with pesticide use leads to informed decision-making in identifying those levels of risk acceptable to society. Risk assessment, product labeling, governmental enforcement, and applicator and consumer education form the foundation of a comprehensive framework to regulate the manufacture, use, and disposal of pesticides, and to ensure that adverse effects on human health and the environment are minimized. Responsible management of pesticide risks and benefits allows optimal benefits in terms of public health, safety, and prosperity.

Pesticide applicator certification holds an individual to a higher standard of conduct and increased duty of care than the noncertified person; that is, every one expects the commercial applicator to closely follow label instructions. But it's more than just a legal argument–follow the label and stay out of trouble. When the applicator closely follows the pesticide label, it means that the human health and environmental predictions made by EPA and the manufacturer will have a better opportunity of being correct. That is, the benefits of use outweigh the risks of use. And in practical terms, it means that your industry will have the pesticides available for use to deal with the pests that attack our farm fields.

## FURTHER INFORMATION

The following publications can be obtained at http://www.btny.purdue.edu/PPP/

- Pesticides and Food Safety (PPP-22)
- Pesticides and the Label (PPP-24)
- Pesticides and the Balancing Act (PPP-33)
- Pesticides and Water Quality (PPP-35)
- Pesticides and the Law (PPP-36)
- Pesticide Toxicology (PPP-40)
- Pesticides and Ecological Risk Assessment (PPP-41)
- Pesticides and Epidemiology (PPP-43)
- Pesticides and Human Health Risk Assessment (PPP-48)

# EPA Rules: From Regulators to Applicators, Where Do We Go?

**JOHN WARD**

Laws governing pesticides are brought about in a democratic society by a large number of individuals or groups that try to standardize conditions by which government oversees some parts of our personal safety, economics, or business conditions. These proposed bills are then developed by elected representatives, and if acceptable to the majority, are made into laws. This process is usually complex, with extensive lobbying, committee markups, and negotiations, but occasionally a bill passes through the process nearly intact. Once the bill is passed into law, it is assigned to an agency or department for implementation. The U.S. Environmental Protection Agency (EPA), for example, has dozens of laws for which it is responsible. Some are mainline statutes such as the Clean Water Act, whereas others, such as those dealing with marine anti-fowling paints, are rarely mentioned.

One of the problems with laws, particularly federal laws, is that they usually are one-size-fits-all. Unfortunately for the regulated industry, there are many circumstances that are unique, and using the same yardstick across the country on a variety of variables seems unjust. Additionally, the laws themselves are very broad and require additional detail to allow implementation. For these and other reasons, rules (or regulations) are developed.

The rules developed under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) are subject to a strict set of requirements. So in a sense, there are rules for making rules. The EPA draws on a variety of input and a firm understanding of the regulatory impact before the rule is drafted. The agency uses many sources of scientific, economic, and social data to draft the proposed rule. While in the development phase, the groups selected to work on the rule are prohibited from discussing it (the black box). The proposed rule is then published in the Federal Register and comments are sought for a certain time. For proposed FIFRA rules, the regional EPA offices solicit comments from state agencies (i.e., Illinois Department of Agriculture) and the state extension services. The EPA also announces the proposed rule to associations and organizations that are impacted. When the comment period is over, the rule-making group sorts, separates, and itemizes all the comments. Depending on the nature of the comments, the rule can either be reproposed as draft or be published as final.

Publishing in the Federal Register is not quite the same as publishing in *USA Today*, or airing the information on a television network. The job of notifying the impacted public falls on many different groups.

Most new rules or rule changes have a delayed effective date, but some laws, rules, or policies go into effect immediately. Some of the FIFRA rules that are found in 40 CFR, Parts 150 to 189, and that impact Illinois agriculture are as follows:

- Registration/reregistration/labeling
- Registration of pesticide-producing establishments
- Worker protection standards
- Certification of pesticide applicators
- Enforcement policies and interpretation
- Plant-incorporated pesticides
- Anticipated rule on protection of groundwater
- Anticipated rule change on storage/disposal

In addition to rules, the Office of Pesticide Programs (OPP) and Office of Enforcement and Compliance Assurance (OECA) develop and publish policies that can significantly impact pesticide applicators and growers.

In this session, I discuss how rules and policies impact the attendees at this conference. Web sites to keep up-to-date on FIFRA regulatory activities are as follows:

- http://www.epa.gov/r5ptb/pest (U.S. EPA Region 5)

- http://www.epa.gov/pesticides (U.S. EPA Office of Pesticide Programs)
- http://www.epa.gov/pesticides/fifra.htm (FIFRA)
- http://www.epa.gov/pesticides/cfr.htm (Pesticide rules)
- http://www.epa.gov/PR_Notices (Pesticide registration notices)
- http://es.epa.gov/oeca/ag (OECA Agriculture Center)

# Invasive Species: What Are They?

**STAN SMITH**

Invasive species–what are they? Animals, bugs, plants, fish, or aliens from outer space? Actually, they could be all of the above. It depends on your job. If you are a water manager, an invasive species could be the round goby, a small fish introduced into the Great Lakes, or the zebra mussel, also introduced into the Great Lakes, and spreading throughout the Midwest watershed; or some type of water plant in your ponds or lakes. If you are a land manager, an invasive species could be a weed, plant, or insect. An invasive species could be any species that is not native to your environment. We think of invasive species as biological material that have been brought into the United States from foreign countries. But plants such as mutiflora rose, purple loosestrife, Japanese honeysuckle, and buckthorn have been around for so long that some people consider them native species that have "gone bad." These and others such as Japanese beetle, gypsy moth, some weeds, and other plant material are not native but have been here so long that they probably should qualify for resident status.

According to the Executive Order 13112 signed by former President Clinton in 1999, an invasive species is an alien species whose introduction does or is likely to cause economic or environmental harm, or harm to human health. To understand this definition we have to define "alien species." Alien species means, with respect to a particular ecosystem, any species, including its seeds, eggs, spores, or other biological material capable of propagating that species, that is not native to that ecosystem. Simply, the definition of a weed, *a plant out of place*, would work for any plant, insect, animal, or fish that is where it doesn't belong.

The Invasive Species Council was established by executive order from former President Clinton. This council has eight cabinet level members, plus a host of government agencies, and includes both public and private institutions. The council's job is to come up with an Invasive Species Management Plan. They are still working on it. However, with the change in administration, and recent events, progress is currently slow.

There are many so-called invasive species throughout the United States. They were brought in for one purpose and later turned out to be a mistake. One of the most glaring mistakes was made in Hawaii, where the mongoose was introduced to control rats (probably introduced by the early explorers) in sugarcane fields. Unfortunately, more research should have been conducted before the introduction because rats are predominately nocturnal and mongoose are active mostly during daylight. Thus, instead of controlling the rats, the mongoose have nearly eliminated the native species of birds from the islands, and very little sugarcane is produced there now. Kudzu is another example of a good idea gone bad. Introduced in the south during the 1930s for erosion control, it soon escaped and has been spreading ever since. In southern Illinois, kudzu has taken over in some areas. The Illinois Department of Natural Resources is trying to eradicate kudzu from the state. I wish them luck, because part of my job is to stop infestations of newly introduced pests from establishing themselves in Illinois. It is not an easy job.

An insect that has had a high profile the last several years in Illinois is the Asian lady beetle. Probably, most soybean farmers in the past few years wouldn't consider this beetle an invasive species, but rather a beneficial one due to the recent invasion of the soybean aphid. However, the Asian lady beetles' habit of swarming around homes (looking for winter shelter) upsets many urban homeowners. It's hard to convince people that these are good insects, when thousands of them are trying to take up residence in their homes. Asian lady beetle is another example of a purposefully introduced species; it was introduced to fight scale insects on peach trees in Georgia.

What other invasive species are in Illinois? Here, I name a few that I am dealing with or have dealt with in the past. But remember that your line of work often influences what you consider to be an invasive species.

Purple loosestrife arrived from Europe and Asia in the 1800s. It is a very pretty plant, but it flourishes in wetlands and forces out native species. Currently, two beetle species are being used in an attempt to curb the population of loosestrife.

Common buckthorn also came in from Europe in the late 1800s. It is very hardy and once established, can become a problem in woodlands and prairies. It also has been found to be the overwintering site for the Asian aphid (soybean aphid) that attacks soybean.

Mutifora rose was introduced in 1800s for various uses: wildlife food and cover, erosion control, and living fences. Once touted as good wildlife habitat, it is now considered an exotic weed by the Department of Natural Resources. Currently, a rose virus is slowing its growth.

Musk thistle, another 1800s introduction from Europe, can be found in roadsides, wastelands, and pastures. This plant is on Illinois's noxious weed list. A weevil that was introduced into Illinois in the late 1970s has shown some promise in reducing populations of this thistle.

Japanese beetle came to the United States in infested nursery stock, and today it can be found almost anywhere east of the Mississippi River. Japanese beetle is a quarantined pest. Plant material, and articles containing soil leaving the state going west, must be certified free of Japanese beetle before leaving Illinois.

Asian tiger mosquito, a relative newcomer, was first discovered in the United States in the mid-1980s. It lives in about anything that holds water, old tires being one of its favorite spots. This mosquito can transmit several viruses to humans, including encephalitis.

As mentioned, zebra mussels have caused a lot of problems. This mollusk arrived from Europe in the ballast tanks of ocean-going ships. It is now found in all of the Great Lakes and has moved into the Mississippi River. Problems caused by this species range from eliminating native mussels to clogging water intake pipes. However, zebra mussels have helped clean some polluted waters because they filter large amounts of water while feeding.

Another pest that arrived in the ballast tanks of ocean-going ships coming into the Great Lakes was the round goby. This small fish reproduces rapidly and has a diverse diet. It feeds on the eggs and young of many native fish species, and also on zebra mussels.

The pests that I currently deal with most of the time include gypsy moth, which has been in the United States since the 1850s, and the Asian longhorned beetle.

We have dealt with gypsy moth in Illinois since 1976. The first eradication treatment was in Palos Park. Since that time, we have treated every year except for two (the 2 yr that followed years that had winters of -26 degrees Fahrenheit). From 1976 to 1998, we were able to eradicate every infestation that was located. Now, however, with eastern Wisconsin being infested right up to our northern border, the front is on our doorstep. Gypsy moth has established a foothold in the northeast corner of Illinois, so it is no longer possible to eradicate it from the state. Lake County was quarantined in 2000. Cook, DuPage, and Mc Henry counties will not be far behind. We have switched from an eradication mode to one of attempting to slow the spread of gypsy moth. More than likely, we will lose the fight in the urban areas around Chicago. Our plan is, at some point in time, to back off to the cornfields and make our stand there.

Asian longhorned beetle is a very destructive insect that attacks certain types of trees, particularly maples and elms. The beetle came to Illinois from China in what is called "solid wood packing material." It was first found in New York City and Long Island in 1996. In 1998 it was found in the Ravenswood area of Chicago, then Addison, and a short time later in Summit. In 1999, it was found in and near a forest preserve near Park Ridge and in 2000 on the grounds of O'Hare Field. The only way to get rid of this pest is to cut down and chip the infested trees. To date, 1,523 trees have been destroyed in Illinois and more than 5,300 have been destroyed in New York. It appears that in Illinois we may be winning the war with this pest. We have not seen a live beetle in any of the areas in more than a year. We have only found 65 infested trees since the beginning of 2001 and none since flight season should have begun. Imidacloprid treatments have been placed in more than 35,000 trees by using Mauget injections. It appears these treatments may be working. If successful treatment continues, we may be able to drop the quarantine in Summit by late 2002, in Addison by 2003, and hopefully the rest by 2005. New York still has a battle on its hands. Their infestations are much larger and more widespread than ours, and they are still finding live beetles and many infested trees.

# Illinois Noxious Weed Law: A Quandary of Enforcement

**TOM WALKER**

Over the past several years, questions have arisen concerning what weeds are listed under the Illinois Noxious Weed Law and who, if anyone, enforces the law. The following plants within the sovereign territory of the State of Illinois are designated and declared noxious weeds:

- marijuana (*Cannabis sativa* L.);
- giant ragweed (*Ambrosia trifida* L.) within the corporate limits of cities, villages, and incorporated towns;
- common ragweed (*Ambrosia artemisiifolia* L.) within the corporate limits of cities, villages, and incorporated towns;
- canada thistle (*Cirsium arvense* L.);
- perennial sowthistle (*Sonchus arvensis* L.);
- musk thistle (*Carduus nutans* L.); and
- perennial members of the sorghum genus, including johnsongrass (*Sorghum halepense* L.), sorghum almum, and other johnsongrass × sorghum crosses with rhizomes.

The law states that every person shall control the spread of and eradicate noxious weeds on lands owned or controlled by that person. The duty of enforcing the Illinois Noxious Weed Law and carrying out its provisions is vested in the Department of Agriculture, and the authorities designated in the Illinois Noxious Weed Law. The Department of Agriculture is authorized to investigate the subject of noxious weeds, and to require information and reports from any control authority as to the presence of noxious weeds, or other information relative to noxious weeds and the control/eradication thereof in localities where such control authority has jurisdiction. Although the legislature originally gave some enforcement authority to the Department of Agriculture, Public Act 79-1017 repealed this authority in 1975 by eliminating all appropriations for controlling noxious weeds.

The Illinois Noxious Weed Law also gave the authority to control noxious weeds to a local control authority. However, counties are not mandated to establish a control authority. If created, they are not mandated to employ any individuals as a weed control superintendent. There are counties in Illinois that have adopted the Illinois Noxious Weed Law by reference and incorporated it into their own weed control programs. Another problem is that any control authority would become a taxing entity and could establish a Noxious Weed Control Fund. Public Act 84-163 repealed the section, in 1968, to establish a Noxious Weed Control Fund by the control authority.

A violation of the law is a petty offense and the violator shall be fined not more than $100 for the first offense and not more than $200 for each subsequent offense. The local state's attorney must file any petty offense.

A quandary does exist within the Illinois Noxious Weed Law. The law mandates that individuals must control noxious weeds, whereas the authority to enforce and fund the programs at the state and local level has been subsequently repealed. Controlling noxious weeds must compete with the other priorities for funding at the local county level. Individuals should work with their local county boards to resolve the issue of controlling noxious weeds by ensuring that any weed program mandated must include the Illinois Noxious Weed Law by reference. In the absence of a weed control program, individuals have to convince their county board that controlling noxious weeds is a priority for the county to pursue.

# Soybean Disease Update: An Overview of Important Soybean Diseases and Results of Current Research Efforts

**DARIN EASTBURN AND BRIAN W. DIERS**

Soybean diseases continue to be one of the most important factors limiting the production of soybean in Illinois. Some of these diseases, such as brown stem rot and Phytophthora rot, and damage caused by soybean cyst nematode (SCN), have been persistent problems, whereas sudden death syndrome (SDS), stem canker, white mold, and bean pod mottle have increased in importance over the past several years. A yearly survey of SDS incidence in each county in Illinois has shown high levels of this disease in northern and central counties for the past few years. The incidence in southern counties has varied from year to year, depending on seasonal temperatures and rainfall. Statewide levels of SDS were lower in 2001 than they were in the previous 2 yr, but relatively high levels of SDS (detected in >50% of fields surveyed) were observed in several counties in east central Illinois. Several research projects on SDS are underway to obtain a better understanding of the mechanisms of disease development, to screen soybean germplasm for disease resistance, to develop resistant varieties, and to determine the mechanisms of disease resistance. Evaluation of germplasm for disease resistance and efforts to develop disease-resistant varieties are also underway for SCN, brown stem rot, white mold, and Phytophthora rot. Bean pod mottle virus has gained attention as a possible cause of late-season green stem, and efforts are underway to determine the nature of this relationship and to evaluate the prevalence of this and other viral diseases on soybean in Illinois.

# Phytophthora Diseases of Illinois Crops

**MOHAMMAD BABADOOST AND DEAN MALVICK**

We discuss several diseases caused by different *Phytophthora* species that damage vegetables, soybean, and alfalfa in Illinois. Phytophthora blight, caused by *P. capsici,* is a serious threat to the production of vegetables, including cucurbits, eggplants, peppers, and tomatoes. This pathogen causes damping-off, foliar blight, and fruit rot. We are developing effective methods to control Phytophthora blight of vegetables with an emphasis on the use of resistant/tolerant cultivars and fungicides. Seven cultivars/lines of bell pepper showed resistance to *P. capsici*, and induction of resistance in pepper, pumpkin, and tomato, by red-light treatment, is promising. Among the fungicides tested for seed treatment, Apron XL LS and Allegiance LS effectively controlled seedling death. Tests of 19 fungicides showed that dimethomorph was the most effective in controlling *P. capsici*. Also, Cuprofix, Ridomil Gold/MZ, and Zoxium suppressed *P. capsici.* Phytophthora rot of soybean (caused by *P. sojae*) is a significant disease of soybean in the Midwest. It kills plants throughout the season and causes sublethal effects on plant health. Management of this disease is based on soybean varieties with race-specific resistance. Races of *P. sojae* have been reported in Illinois and bordering states that can overcome resistance genes in soybean, including the widely effective Rps genes 1a, 1c, 1d, and 1k. Phytophthora root rot of alfalfa (caused by *P. medicaginis*) is another widespread and destructive disease. This disease can affect alfalfa at all ages, causing destruction of seedlings in new stands and severe root rot in established stands. Management of is based on improving soil drainage and use of resistant alfalfa varieties.

# Organic Matter Management and Carbon Sequestration

MICHELLE WANDER

## NEED AND POTENTIAL FOR CARBON (C) SEQUESTRATION

Carbon dioxide is accumulating in the atmosphere at a rate of 3.5 billion metric tons per year and this increase is expected to cause observable shifts in climate in this century. The Kyoto Protocol to the UN Framework Convention on Climate Change was initially conceived in 1995; signed by 100 countries, including the United States in 1997; and finally ratified by 178 nations on 22 July, 2001. The United States, the largest source of greenhouse gasses (GHGs) did not participate. The pact will require developed nations to reduce their emissions of greenhouse gases during the period 2008–2012 to pre-1990 levels. Strategies for reductions include reduced emissions of several greenhouse gases and net removal of $CO_2$. Compromises in enforcement language and penalties for countries that fail to meet reduction targets and allowances for trade-off mechanisms to allow credits for C sequestered in forests and farmland projects were key to Japan's participation in the treaty. Environmentalists have been highly critical of offset allowances because they will substantially reduce actual reductions in emissions.

It is clear that agricultural soils could sequester significant amounts of $CO_2$. Many sources suggest that over the next 50–100 yr, the world's agricultural soils could remove 40–80 billion metric tons of carbon from the atmosphere. The agricultural soils of the United States might sequester 17–39 metric tons of carbon/yr (Lal et al., 1998). The potentially large initial contribution of soils to emission reductions has actually caused some to oppose the use of agricultural and forested lands in Kyoto Protocol calculations. Critics fear that annual accumulation of C in agricultural soils, which might be partially achieved by accounting of previously undocumented stocks, could be large enough to greatly diminish the impact of the accord on energy-related emissions. Concerns also have been raised about 1) the uncertainty of benefits accrued to specific land management practices, 2) our capacity to evaluate or verify outcomes in a timely and affordable manner, 3) the limited amount of information relating C sequestration to associated environmental impacts, and 4) our ability to account fully for practice impacts on other important GHGs ($NO_2$ and $CH_4$).

The potential for C sequestration in agricultural lands has been discussed at other levels in addition to the policy level. Farmer interest in soil organic matter management and carbon sequestration has grown rapidly during the last few years due to the prospect they might receive payments for carbon credits. In 1996, Canadian energy firms established the Greenhouse Emissions Management Consortium (GEMCo) to develop commercial mechanisms for trading agricultural carbon credits. One of their stated goals was to invest in sustainable land management practices that enhance the C content of soils in the medium term and the viability of farms in the long term. This goal became relevant to Illinois farmers when the Iowa-based IGF Crop Insurance Company agreed to broker carbon emission reduction credits (CERCs) for GEMCo. A CERC, the equivalent of 1 metric ton of atmospheric carbon dioxide reduced or avoided from an agreed baseline, can be generated by documenting activities that provide a net "sink" or actual reduction of emissions by avoidance or substitution. Once created, CERCs do not expire or exhaust themselves, i.e., sequestered C should be committed to a permanent sink. The CERCs are awarded for agricultural practices such as minimum-till and no-till farming practices, cropland retirement, buffer strips, afforestation, reforestation, improved timber management, power generation from biomass, and methane abatement from livestock waste.

## CHALLENGES THAT NEED TO BE OVERCOME

It is vital that we are not too far off in our estimations for soil C storage potential. Experts agree that at present we do not have models with the predictive capacity to estimate C flux across the gradient of management and soil conditions needed. Many of the projections for C sequestration by agricultural soils have used yield trends as inputs to drive empirical models to predict future soil C stocks (Donigan et al., 1995). Use of yield trends and not actual trends in C stocks as a basis for prediction is a serious deficiency in these models. The influence of cropping practices on soil C contents depends on many factors, including the condition of the soil being managed. Results from a long-term study conducted at two sites in Wisconsin can be used to demonstrate several important points (Table 1).

**Table 1. N fertility, crop rotation, yield, and changes in soil C storage.**

| Nitrogen Treatment[a] kg ha$^{-1}$ | Rotation | Corn Yield kg ha$^{-1}$ | Residue Returned t ha$^{-1}$ | Change in Organic C g C kg$^{-1}$ | Rate of Change g C kg$^{-1}$ yr$^{-1}$ |
|---|---|---|---|---|---|
| *Arlington* | | | | | |
| 0 | CC | 3760 | 67 | 0.040816 | 0.001633 |
| 84 | CC | 6632 | 91 | 0.145455 | 0.005818 |
| 168 | CC | 7047 | 94 | 0.153153 | 0.006126 |
| *Lancaster* | | | | | |
| 0 | CC | 3261 | 56 | –0.15 | –0.00682 |
| 84 | CC | 6106 | 76 | –0.31967 | –0.01453 |
| 168 | CC | 6920 | 82 | –0.18382 | –0.00836 |
| 336 | CC | 7447 | 86 | –0.21053 | –0.00957 |
| 0 | CCOAA | 7000 | ND | 0.01227 | 0.000558 |
| 0 | CSOA | 7900 | ND | 0.006173 | 0.000281 |
| 0 | AC | 8000 | ND | –0.05229 | –0.00238 |

Data from Vanotti et al. (1997).

[a] Experiment had been in place for 25 yr in Arlington and 22 yr at Lancaster. CC, continuous corn; CCOAA, CCOAA, and CSOA represent rotations of corn, soybean, oats, and alfalfa; AC, alfalfa corn rotation.

In both sites in the CC plots, corn yield and the amount of crop residue returned to the soil increased with nitrogen (N) application rate. At the Lancaster site, corn yield in rotation plots that included alfalfa equaled or exceeded the highest yield obtained in the CC plots without fertilizer N application. At the Arlington site, increases in organic C content were positively related to residue return rates. In similarly managed CC plots at the Lancaster site, organic C was actually lost from all plots and the magnitude of that loss was not diminished by increasing amounts of residue returned. Organic C also was lost from that site in the AC rotation plots; only the CCOAA and CSOA plots accumulated C during the 22-yr trial. These two sites did not differ in their responsiveness to management because of the quantity of organic C they contained at the start of the experiment; the soil at the Arlington site was a Mollisol that had a C content of 18.8 g kg$^{-1}$ soil and the Lancaster site the soil was an Alfisol with a C content of 16.1 g kg$^{-1}$ soil. It may be that the soil at the Lancaster site was at or near its saturation capacity for organic C and that the quality of the organic matter was very high because that site had been in alfalfa-bromegrass pasture before the experiment was begun.

Because of this uncertainty, some have cited a need for assessment and validation techniques, whereas others argue against farm or field-level sampling, citing the high cost of on-site soil carbon monitoring. Beyond cost limitations, there are several practical factors that limit the usefulness of soil sampling in the short term as basis for program success. The first problem is that it may take a decade or more before changes in soil organic C content become apparent, a second problem is that farmers who participate in programs do not control all of the factors influencing C balance in their soils. A catastrophic flood or prolonged drought could offset or totally undermine any improvements to soil C balance despite a farmers use of best management practices. Should farmers who adopted all the recommended practices be rewarded on the basis of how much C they sequester or regardless of the outcome? During the early stages of a C credit program, it is most likely that producers will be rewarded based on probable rather than actual outcomes.

## MANAGEMENT, C SEQUESTRATION, AND MITIGATION OF GLOBAL CHANGE

What are the probable outcomes for soil C sequestration? To estimate what might be expected for Midwest soils, I summarized long-term studies from Corn Belt states that recorded the influence of management practices on soil organic carbon (SOC) concentrations in the top 20-30-cm depth (Table 2). The SOC concentrations of conventional treatments (tilled plots with continuous corn or corn and

**Table 2. Soil carbon sequestration potential in the Midwest.**

| Cropping System | C Sequestration Potential kg C $ha^{-1}$ $yr^{-1}$ |
|---|---|
| Conventional continuous corn | 0 |
| No-till continuous corn | 116 |
| Diversified rotation: corn-soy-wheat, fertilizer based | 203 |
| Diversified rotation: corn-soy-wheat, manure based | 791 |
| Diversified rotation: corn-soy-wheat, legume based | 998 |
| Diversified rotation/reduced tillage: C-S-W, legume based | 3029 |

Data from Dick et al. (1991), Robinson et al. (1996), Lesoing and Doran (1997), Paustain et al. (1997), Vanotti et al. (1997), Aref and Wander (1998), Hussain et al. (1998), Lal et al. (1998), Wander et al. (1998), Drinkwater et al. (1999).

soybean grown in rotation) were the controls used as denominators against which SOC contents of soils under alternate management were compared. For all treatment categories, the mean percentage of change in SOC was computed; this value was then divided by the mean duration of the experimental trials that were compared (%$Change_{no\text{-}till}$/ years $under_{no\text{-}till}$). The resulting rates of change were converted to an area basis by multiplying these values by the SOC control concentration and then converting g C $kg^{-1}$ soil $year^{-1}$ (to 20-cm depth) to kg C $ha^{-1}$ $year^{-1}$ by multiplying by 2900 for tilled treatments or 2940 for no-till treatments.

This summary suggests that adoption of reduced or no-tillage practices increases C sequestration rates compared with tilled soils and that diversification of cropping systems increases sequestration potential even more. Data from the region suggests that cropping systems that substitute organic sources of fertility or reduce tillage in a diversified cropping system have the potential to sequester C at very high rates. This point is well supported in the scientific literature. For example, Lee et al. (1993; Table 3) used the EPIC model to estimate 100-yr changes SOC contents at 100 randomly selected sites in the Corn Belt that would result from increased adoption of no-till practices. They showed that the base trend toward use of no-till practices would increase SOC in the surface depth and that increased use of no-till practices, and especially increased use of no-till practices combined with a winter wheat cover crop, would increase C concentrations in the surface soil. Approximately 21% of the loss in C was attributed to erosion-based losses. When SOC contents were considered to a 1-m depth, as they should be for C accounting purposes, SOC levels declined in all cases except where tillage was reduced and crop diversity was increased. Assessments of management systems based on samples from only the surface depth should be viewed with caution. In this region, cropping system diversification should be considered at least as important as tillage reduction for increased C sequestration.

Carbon dioxide is not the only greenhouse gas. Agriculture has been cited as a major source for other important GHGs ($NO_2$ and $CH_4$). Recently, Robertson et al. (2000) assessed the influence of agricultural and alternate land-use practices on SOC contents measured, but unfortunately, only to a 10-cm depth (Table 4). They found that the no-till system sequestered the most C. If they had measured SOC stored in the top foot, or to a meter depth, the result may have changed. The global warming potential (Table 5) of each system was then estimated based on C sequestration, agronomic inputs, and GHG emissions. None of the agronomic systems were able to mitigate global change by acting as a net sink for GHGs. The No-till system was performed the best, and this result was based primarily upon presumed changes in total SOC. All of the systems produced $N_2O$, which has a heat trapping capacity of >300 times that of $CO_2$. In the conventional till system, which has a C-S-W rotation, $N_2O$ is single greatest contributor to GHG emissions; the remaining 50% of GWP comes from fuel and fertilizer use.

**Table 3. Changes in soil C: 100-yr management scenarios in the Corn Belt.**

| Scenario | Top 15 cm | 1-m Depth |
|---|---|---|
| | tons C $ha^{-1}$ | |
| Current tillage mix | –4 | –123 |
| Base trend | 13 | –86 |
| Increased no-till | 37 | –39 |
| Increased no-till & cover crop | 73 | 3 |

Data from Lee et al. (1993).

**Table 4. Michigan LTER: means or trends from 8 yr.**

| Cropping system: CSW | ANPP MT $ha^{-1}$ $y^{-1}$ | SOC kg $m^{-2}$ | DC g $m^{-2}$ $y^{-2}$ |
|---|---|---|---|
| Conventional till | 9.24 | 0.94 | 0 |
| No till | 9.19 | 1.24 | 30 |
| Low input + legume cover | 8.84 | 1.05 | 11 |
| Organic + legume cover | 7.79 | 1.02 | 8 |
| Early succession | 4.24 | 1.54 | 60 |
| Late successional | 5.26 | 2.29 | 0 |

Data from Robertson et al. (2000).
ANPP, annual net primary productivity; DC, change in SOC that occurred during the 8-yr study.

**Table 5. Global warming potential of Michigan LTER cropping systems: in $CO_2$ equivalents.**

| Cropping System: CSW | $CO_2$ | $N_2O$ | $CH_4$ | Net GWP |
|---|---|---|---|---|
| | | $g\ m^{-2}\ y^{-2}$ | | |
| Conventional till | 72 | 52 | –4 | 114 |
| No till | –47 | 56 | –5 | 14 |
| Low input + legume | 8 | 60 | –5 | 63 |
| Organic + legume | –10 | 56 | –5 | 41 |
| Early successional | –220 | 15 | –6 | –211 |
| Late successional | 0 | 21 | –25 | –4 |

Data from Robertson et al. (2000).

## SUMMARY

There are several issues that will determine whether C credits are awarded to producers for altering their agronomic practices. Resolution of article 3.4 of the Kyoto Protocol, to determine whether and how C sequestered in agricultural lands can be deducted from emission reduction commitments will be critical. If agricultural C sinks are approved then scientists and economists will need to work hard to avoid pressures to accept politically expedient solutions that will not lead to actual reductions in green house gas emissions and $CO_2$ levels. In the future, documentation of benefits of soil C sequestration to soil and crop quality, water quality, wildlife habitat, and cropping system efficiency would to help build lasting public support for this kind of program. Ultimately, strategic sampling protocols will be needed to improve and demonstrate the success of C credit programs.

## REFERENCES


Donigan, A.S., Jr., A.S. Patwardhan, R.B. Jackson, 4th, T.O. Barnwell, Jr., K.B. Weinrich, and A.L. Rowell. 1995. Modeling the impacts of agricultural management practices on soil carbon in the central U.S., in *Soil Management and Greenhouse Effect* (R. Lal, J. Kimble, E. Levine, and B.A. Stewart eds), pp 121-136, Lewis, Boca Raton, FL.

Lal., R., Kimbel, J.M., Follett, R.F., and C.V. Cole. 1998. The Potential of U.S. Cropland to Sequester Carbon and Mitigate the Greenhouse Effect. Ann Arbor Press, Chelsea, MI.

Lee, J.J., D.L., Phillips, and R. Liu. 1993. The effect of trends in tillage practices on erosion and carbon content of soils in the US Corn Belt. *Water, Air, and Soil Pollution* 70: 389-401.

Robertson, G.P., E.A. Paul, and R.R. Harwood. (2000) Greenhouse gases in intensive agriculture: contributions of individual gases to the radiative forcing of the atmosphere. *Science* 289: 1922-1925.

# Three Certainties in Life: Death, Taxes, and Weeds

AARON G. HAGER, LOYD M. WAX, AND JERRY DOLL

## HOPHORNBEAM COPPERLEAF (*ACALYPHA OSTRYIFOLIA*)

**Aaron Hager**

Hophornbean copperleaf is a summer annual species in the Euphorbiaceae family. This plant family, also known as the Spurge family, includes several other problematic weed species, many of which have a milky sap. Hophornbeam copperleaf, however, does not contain the characteristic milky sap of other Euphorbiaceae. It is indigenous to Illinois and most commonly found in the southern third of the state. Over the past 6 yr, however, populations have been identified in corn and soybean fields progressively farther north, and in 2001, samples of a hophornbeam copperleaf population from the Lee County area were received for identification. Several other copperleaf species can be found in Illinois, and although most of these other species are not considered problematic in agronomic production systems, Virginia copperleaf (*Acalypha virginica*) can be a troublesome weed species in southern Illinois.

### Hophornbeam Copperleaf Morphology and Biology

Hophornbeam copperleaf has pubescent cotyledons and true leaves with short hairs and finely toothed (serrated) margins. The leaves are simple and alternate and somewhat heart-shaped at the base. As plants become larger, a reddish coloration is often observed where the main leaf vein intersects the petiole. Hophornbeam copperleaf may sometimes be misidentified (especially during early vegetative development) as prickly sida (*Sida spinosa*), but certain morphological characteristics can be used to differentiate these two species. The leaf margins of prickly sida are more coarsely serrated than those of hophornbeam copperleaf, and hophornbeam copperleaf does not have the small stipules (spines) in the leaf axils like prickly sida.

Hophornbeam copperleaf is monoecious (both male and female flowers on the same plant), with staminate (male) flowers produced on axillary spikes and pistillate (female) flowers produced on a long, terminal spike. Seeds capsules of hophornbeam copperleaf are three-lobed and dehiscent (capsules split open at maturity to release seed), and seeds appear to require warm temperatures for germination. A warm soil temperature germination requirement suggests this species is able to germinate and emerge later during the growing season. Emergence can begin in late May or early June and may continue for most of the growing season. Additional flushes of hophornbeam copperleaf frequently appear after precipitation. Recent experience has shown that hophornbeam copperleaf can be present during corn or soybean harvesting operations, and that many of the plants probably emerged after the crop reached full maturity. A recently published experiment reported the average seed production of hophornbeam copperleaf plants growing alone (without competition) was approximately 12,518 seeds per plant, much greater than the average seed production (980 seeds per plant) when grown with soybean. No data are available that describe seed longevity in the soil or potential seed dormancy.

## GIANT RAGWEED (*AMBROSIA TRIFIDA*)

**Loyd M. Wax**

Giant ragweed is a native of the Midwest and is one of the most troublesome weeds in corn–soybean rotations in some locations. Research in the 1960s and 1970s showed that virtually all giant ragweed seeds germinated very early in the season. Tillage and planting resulted in relatively

few giant ragweed problems in most fields. Then, this weed was found mainly in undisturbed areas and sometimes in fields in flood plains. Over the last decade, giant ragweed has spread throughout fields in many areas. Giant ragweed is one of the most competitive weeds found in either corn or soybean. Research in Illinois in recent years has shown that the emergence period of giant ragweed appears to be shifting to a later germination pattern, partially resulting in greater problems. Other factors, such as earlier planting and less tillage before planting, also contribute to the problem.

Control with herbicides can be very good but often is inconsistent, especially with many soil-applied herbicides, because the weed can emerge from considerable depths and at various times. Postemergence control may be inconsistent because the weed often gets too large and then regrows after treatment, as well as emerging after treatments are completed. The development of resistance to some herbicides has limited the options in some areas. Giant ragweed seeds can remain viable for a number of years in the soil. Growers with heavy infestations should plan a management program and stay with it for several years for optimum results. Undisturbed areas, such as fencerows, roadsides, and waterways near fields often provide the source of seeds for spread into fields. Current research is investigating the emergence and longevity of giant ragweed seeds, various aspects of competition, and improved management systems.

## OTHER IMPORTANT SPECIES

Jerry Doll

Mother Nature seems to never sleep. If we use the same crop production system for many years, she responds with a change in the weed spectrum. And if we change from one tillage system to another, again the weed complex changes. Even in noncropped areas new and different weeds appear. Listed below are some of the weeds increasing on the Wisconsin landscape. Similar changes are probably occurring in Illinois. I discussed several of these weeds with you last year but they are still important and often unrecognized by our producers, therefore I present three of them again.

### Wild Four O'clock (*Myrabilis nyctaginea*)

This taprooted perennial is native to the United States. It has spread from its home in the southwest along rail and highway corridors and now stretches from Texas to Maryland. We first received reports of it in no-till fields, but in recent years it is just as common in chisel-plowed and other reduced tillage systems. Plants thrive in shallow, gravelly soils (thus its frequency in rail and highway systems) but are probably able to grow and compete in many soil types. When plants grow undisturbed, roots can be 2.5 to 3 inches in diameter. Wild four o'clock is a prolific seed producer. Seeds germinate in early May and seedlings appear well into the growing season. Emergence from roots occurs over an extended period as well. Little additional information on the biology of wild four o'clock is known.

Plants are easily identified. Weed books describe the roots as fleshy but they seem to be somewhat woody under Wisconsin conditions. Plants grow 2 to more than 3 ft in height and have erect, branched stems with conspicuous nodes that are particularly evident after leaf drop. Stems are often four-sided but are not as square as those of plants in the mint family. Leaves are opposite, simple, heart-shaped (resemble a lilac leaf), and 1 to 3 inches in length, usually with a pointed tip. Leaves have a short petiole and are widely separated on the stem. The inflorescence is an umbel of terminal clusters, each cluster with one to five flowers. Individual flowers are perfect, have no petals, and are bell-shaped with pink to reddish purple sepals (calyx). Seeds are oblong, grayish brown to yellow, and warty or wrinkled with five ribs that are approximately 3/16 inch in length. The large, tough taproot; the opposite lilac-like leaves; branched, squarish stems; and the pink to reddish flowers that open in the late afternoon and close in the late morning easily distinguish wild four-o'clock from other plants.

### Comfrey (*Symphytum officinale*)

Comfrey is native to Russia and was introduced into the United States from Europe as a medicinal herb. It also has been used as a forage crop. Medicinal and herbal tea uses have come into disfavor because the plant contains alkaloids that can cause serious health problems if consumed in excess or over long periods. Once established, comfrey is very difficult to eradicate. Our infestations are most often the result of a garden being converted into a field. The shift from moldboard plows and disks to chisel plows and tined secondary tillage tools has undoubtedly spread comfrey roots from their original sites. Plowing also results in comfrey emerging over a very extended period.

Plants are 2 to 4 ft in height and have many large, dark green, hairy leaves that arise from the crown and feel somewhat sticky. Leaves are up to 8 inches in length, have no petioles, and flow into the stem, giving it a winged appearance. Comfrey flowers are bell-like, blue, pinkish or white, and are borne in one-sided clusters on curved stalks, as is typical of plants in the Borage family. A pair of wing-like leaves is present at the base of each flower

stalk. Plants seldom produce viable seed but have many thick, branched, brownish to black taproots that can reach 9 ft in depth. Plants propagate readily from root fragments. Little is known about the biology of comfrey under field conditions.

### Giant Chickweed (*Myosoton aquaticum*)

Giant chickweed is native to Europe. The species name suggests plants grow in wet habits, but giant chickweed was first observed in upland pastures of southwestern Wisconsin in the early 1980s. Since then it has spread to many areas of the state, and in recent years has been a weed of concern in numerous pastures, hayfields, and several cropped sites. Once established, plants spread by the semiprostrate stems and seed. Patches of giant chickweed quickly dominate pasture species by shading. Livestock appear to avoid feeding on giant chickweed, allowing the weed to spread and produce seed abundantly.

Leaves are larger than those of mouse-ear and common chickweed. They are opposite and have no petioles. Stems are angled, tend to grow horizontally initially and become erect and reach heights of 8 to 12 inches. Typical of many plants in the Pink (chickweed) family, the five petals are split, giving the appearance of having 10 petals. Fruits are borne on short stalks that bend downward when mature and the stalks are covered with hairs that exude a sticky juice.

### Two Old Friends

Common dandelion (*Taraxacum officinale*) and white cockle (*Lychnis alba*) are becoming increasing problems in no-till soybean. Both have been in the region for many decades and have caused problems in alfalfa for years. The key to success in handling these weeds in no-till soybean is to start with a clean slate, and control them with either a fall treatment or a spring burndown program. Fall treatments are preferred but are difficult to do in a corn-bean rotation. If soybean is planted after wheat or alfalfa, the window for a fall application is very wide. Dandelion is easily controlled by several growth regulator herbicides but not by glyphosate. Our research has shown that dicamba plus diflufenzopyr (Distinct) is often superior to dicamba alone or 2,4-D. Dicamba cannot be used in a spring burndown treatment before planting soybean but it could be used in the fall. We have found that glufosinate (Liberty) has surprisingly good activity on dandelion but again this activity is of no help in the soybean phase of the rotation.

White cockle is more difficult to handle. 2,4-D does not control white cockle (nor any other plants in the Pink family). Glyphosate and dicamba are effective but dicamba has little to offer in the soybean phase of the rotation. To avoid repeated use of glyphosate in the same growing season, we suggest a burndown based on paraquat or chlorimuron + thifensulfuron (Synchrony) tank mixed with 2,4-D ester, followed by an application of glyphosate in a glyphosate-resistant soybean variety. The competition provided by no-till soybean in narrow rows following the in-crop glyphosate application rounds out the control of dandelion and other weeds.

### Others to Look For

Pokeweed (*Phytolaca americana*) and cutleaf teasel (*Dipsacus laciniatus*) deserve mention. Wisconsin thus far has only scattered infestations of pokeweed. My home farm in Bond County, Illinois, was a good example until recently. My brothers now have serious pokeweed infestations in several no-till soybean fields and I know they are not alone and that pokeweed occurs all the way to northern Illinois. Plants produce many seeds in the juicy, purple berries and once established they form impressive taproots. Pokeweed is a perennial and, like dandelion, regrows from the taproot each spring unless vigorous tillage is done.

Cutleaf teasel is seldom if ever an economic concern but it is invading new territory along roadsides and occasionally pastures. Missouri recently declared both cutleaf and common teasel (*T. fullonun*) as noxious weeds. Cutleaf teasel is becoming more common along the roadsides in southern Wisconsin. Teasel is a biennial and thus new plants arise only from seed. Single plants produce thousands of seeds, so a vigorous program of cutting bolted plants and spraying or digging plants in the rosette stage is necessary to prevent further spread.

## IDENTIFYING NEW WEEDS

Plant identification is both a challenge and a necessity. Even in this era of transgenic crops, accurate records on the weeds present during the season are an essential component of integrated cropping systems. Be sure you have the necessary identification manuals to key out the species you find. In addition to *Weeds of the North Central States*, these books are among my favorites:

*Weeds of the Northeast* is one of the newest and also one of the best weed identification references. It contains nearly 300 species, some of which are not found in either the *Weeds of the North Central States* or *Ontario Weeds*. This book is one of the few to include woody species, which are more common on Conservation Reserve Program land and in long-term no-till fields. The book contains five "short cut identification tables" that identify

weeds with special characteristics and a standard dichotomous key for all species that is based on vegetative characteristics. Each weed has four or more colored pictures, a narrative (including a useful description of how to distinguish from similar weeds), and line drawings of key characteristics of certain weeds.

*Ontario Weeds* contains excellent black-and-white line drawings of 315 species with 28 pages of color plates. This book is an excellent match for our weed spectrum. The current edition is out of print and a new one will be available soon. It will be worth the wait.

*Weeds of Nebraska and the Great Plains* has excellent color photos and black-and-white line drawings of 265 species (and descriptions of an additional 125 species) on nearly 600 pages in a hard-bound book. One of its unique features is the section on "uses and value" for most species.

# Using Herbicide Mode of Action to Improve Crop Diagnostic Skills

**JEFFREY L. GUNSOLUS**

Herbicide mode of action is the sequence of events that must occur if a herbicide is to effectively kill a plant species. To be effective, herbicides must 1) adequately contact plants; 2) be absorbed by plants; 3) move within the plants to the biochemical site of action, without being deactivated; and 4) reach toxic levels at the site of action. Failure to meet any of these steps can result in survival of the weed. Failure to understand the herbicide mode of action process also can result in herbicide-induced crop injury.

An interactive CD-ROM addressing herbicide mode of action and crop injury symptoms has been in use since August 1999. The target audience is agricultural professionals and undergraduate agronomy students. This CD-ROM explains how herbicides, human decisions, and environmental factors impact herbicide effectiveness, crop selectivity, and herbicide resistance. It also can be used as a field diagnostic tool, with more than 500 color photos and images and easy navigation through multiple layers of information. A find-it-fast index, illustrated glossary, crop photo library, and Internet connection to herbicide mode of action Web sites also makes it an excellent reference tool. This interactive CD-ROM combines the benefits of video, slides, and print to teach the basic concepts of herbicide mode of action and is designed to work on most PC and MAC platforms.

# The Illinois Nitrogen Soil Test

ROBERT G. HOEFT, RICHARD L. MULVANEY, AND SAEED A. KHAN

## INTRODUCTION

Nitrogen (N) fertilizer recommendations for corn production are often estimated on the basis of a realistic yield goal, with adjustments to allow for N credits from other sources, such as legumes or manure. A yield-based recommendation may have merit on a long-term basis, but under- or overfertilization is apt to occur in any given growing season because soil N availability is not taken into account. Insufficient application of N can have serious economic consequences for the farmer, whereas excessive fertilization increases the risk of environmental pollution.

Public concern that excessive N fertilization may contribute to $NO_3^-$ enrichment of surface and groundwater has stimulated interest in soil testing to improve the accuracy of N fertilizer recommendations for corn. This concern may well be justified, because crop responsiveness to N fertilization can vary widely even within the same field (Harrington et al., 1997), and nonresponsive sites have been detected throughout the north central and northeastern United States (Bundy and Malone, 1988; Fox et al., 1989; Meisinger et al., 1992; Brown et al., 1993; Schmitt and Randall, 1994). For many years, a preplant $NO_3^-$ test (PPNT) has been used in western Canada and the Great Plains region of the Unites States to account for carryover of mineral N from previous cropping (Dahnke and Johnson, 1990; Bundy and Meisinger, 1994). Although originally developed for use in semihumid areas where leaching is limited, the PPNT has recently been applied in humid regions of the north central United States to detect residual $NO_3^-$ in the surface 60 cm (2 ft) of medium- to fine-textured soils (Bundy and Malone, 1988; Schmitt and Randall, 1994). To improve the reliability of $NO_3^-$ testing as a basis for fertilizer recommendations in humid regions, a presidedress $NO_3^-$ test (PSNT) was developed by Magdoff et al. (1984), in which soil sampling is postponed until corn is 6–12 inches in height, so as to estimate plant-available $NO_3^-$ as closely as possible to peak uptake by the crop. If the test indicates a low concentration of soil $NO_3^-$-N (<20–30 ppm), supplemental N is applied as a sidedressing. The PSNT has been recommended more widely than the PPNT in the eastern Unites States, but use has been limited by the need to collect soil samples during the growing season at a time when farmers are occupied with many other tasks that cannot be neglected. Fertilization must be postponed until after testing, and this delay can lead to crop N deficiency if adverse weather conditions prevent sidedressing. Neither test is currently recommended in Illinois.

Numerous chemical methods have been proposed to estimate the availability of soil organic N (Bundy and Meisinger, 1994), but these methods have been based on an empirical approach, and their use has been very limited due to low correlations with crop N uptake and the production of mineral N during soil incubations. A more rational approach would require chemical fractionation of soil organic N to identify a labile pool; however, little progress has been made in this respect, due largely to fundamental defects in the available methodology that vitiated analyses for amino sugar-N and amino acid-N. These defects were identified and eliminated through a substantial effort that ultimately led to simple diffusion methods of fractionating the N in soil hydrolysates (Mulvaney and Khan, 2001). When the newly developed diffusion methods were applied in comparing N-distribution analyses for soil samples from sites that differed in crop responsiveness to N fertilization in a N-response study by Brown et al. (1993), a much higher concentration of amino sugar-N was observed for nonresponsive than for responsive soils (Figure 1), whereas no consistent difference was detected in their concentrations of total hydrolyzable N, hydrolyzable $NH_4^+$-N, or amino acid-N

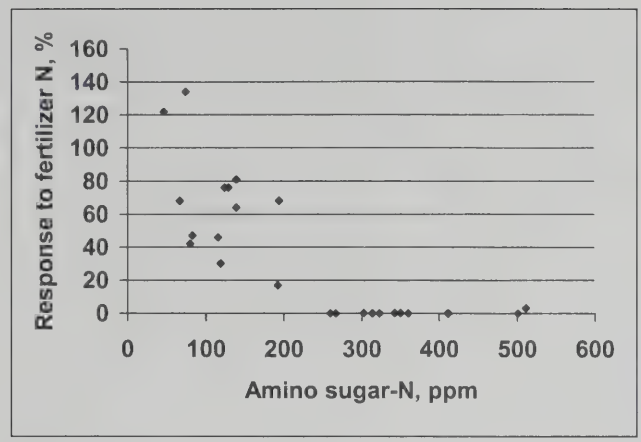



**Figure 1. Effect of amino sugar-N concentration on relative yield response.**

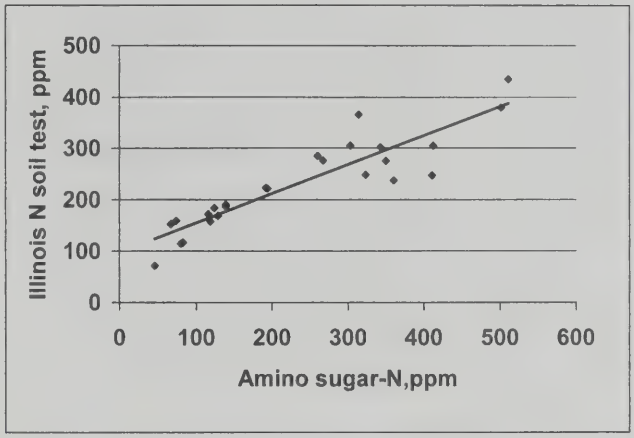



**Figure 2. Relationship between amino sugar-N and Illinois soil test N concentrations. Y = 98.73 + 0.56x, $r^2$ = 0.82.**

(Mulvaney et al., 2001). In subsequent incubation studies, nonresponsive soils produced a much larger quantity of mineral N than did responsive soils, and mineralization was accompanied by a net decrease in amino sugar-N but not in amino acid-N (Table 1).

The method described by Mulvaney and Khan (2001) for determining hydrolyzable amino sugar-N was too tedious and time-consuming for routine use in commercial soil testing laboratories, so a simpler technique was subsequently developed, whereby amino sugar-N is estimated without the need for acid hydrolysis (Khan et al., 2001). The objectives of the present article are to describe how this technique was developed, and to identify some of the factors that must be considered in using it.

## DEVELOPMENT OF A SIMPLE N SOIL TEST

The soil samples used had been collected from the surface 12 inches in late March to early April 1990, 1991, or 1992 from a series of N-rate experimental sites that had been characterized as responsive or nonresponsive by Brown et al. (1993). Soon after collection, the samples were air-dried, ground to pass a 0.15-mm screen, and stored in a Mason jar sealed with an airtight lid. A total of 25 samples, including 12 from nonresponsive and 13 from responsive sites, was then subjected to a series of studies in developing a simple test that would estimate amino sugar-N without the need to hydrolyze the soil for 12 h with 6 M HCl (Mulvaney and Khan, 2001). In the soil test thereby developed, a 1-g sample of air-dried soil is treated with 10 ml of 2 M NaOH in a 1-pint, wide-mouth Mason jar, and the jar is gently swirled to mix the contents (but not so vigorously as to deposit some of the sample on the wall of the jar) and then sealed within 15-30 s by attaching a lid modified to support a small petri dish containing 5 ml of $H_3BO_3$ indicator solution. The sealed jar is heated on a hot plate (i.e., a commercial griddle) for 5 h at a temperature of 48-50°C. After removing the petri dish from the jar lid, the $H_3BO_3$ solution is diluted with 5 ml of deionized water and subsequently titrated with 0.01 M $H_2SO_4$, either manually or by using an automatic titrator. The micrograms of N liberated by diffusion is calculated as $S \times T$, where $S$ is the volume of $H_2SO_4$ used in titration of the sample and $T$ is the titer of the titrant (for 0.01 M $H_2SO_4$, $T$ = 280 µg N/ml). For complete details, see Khan et al. (2001).

In comparative studies using the 25 soil samples previously mentioned, soil N-test values were highly correlated with hydrolyzable amino sugar-N (Figure 2). Higher test values were obtained for nonresponsive than for responsive soils, and the two groups were completely resolved assuming a critical concentration of 240 ppm (Figure 3). Test values for nonresponsive soils ranged from 237 to 435 ppm, as opposed to a range of 72 to 223 ppm for responsive soils, which tended to be inversely related to N-fertilizer response. The former range suggests a means of estimating residual N availability, whereas the latter is indicative of a quantitative basis for N rate recommenda-

**Table 1. Net change in inorganic, amino acid, and amino sugar N following a 12-wk incubation of soils differing in N fertilizer responsiveness.**

| | Extractable Inorganic N | Amino Acid (mg N/kg) | Amino Sugar |
|---|---|---|---|
| Nonresponsive soils (3) | 123 | 40 | –46 |
| Responsive soils (2) | 40 | 11 | –23 |

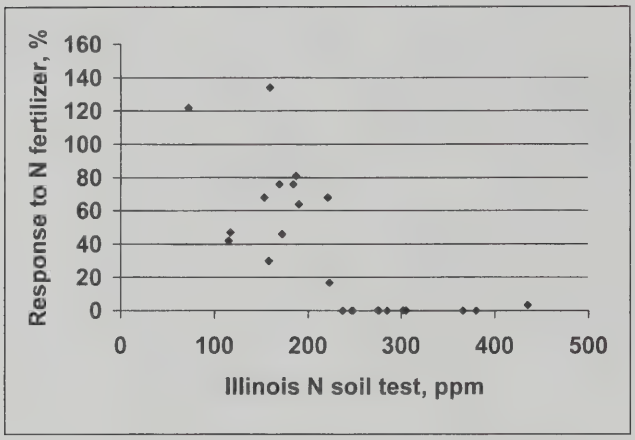



**Figure 3. Relationship between Illinois soil N test and fertilizer N response.**

tions. In either case, much more research is required to ensure adequate reliability in production agriculture.

## Diffusion timing

A 5-h diffusion period was adopted in the N soil test, because this period was adequate to clearly distinguish between responsive and nonresponsive soils (Figure 4), while providing stable test values for responsive soils and allowing commercial laboratories the option of analyzing two sets of samples per day. The latter option could be easily implemented, for example, if heating is initiated late in the day, and automatically discontinued after 5 h by using hot plates equipped with electrical timers. The titrations could be done the next morning, preferably after initiating another set of diffusions. In this manner, five hot plates could be used to process more than 100 samples within a single working day. Studies have shown very little change in soil-test N when samples are allowed to stand for several hours at room temperature following heating, whereas a substantial increase can occur when heating is prolonged beyond 5 h, or is carried out above 50°C (Khan et al., 2001).

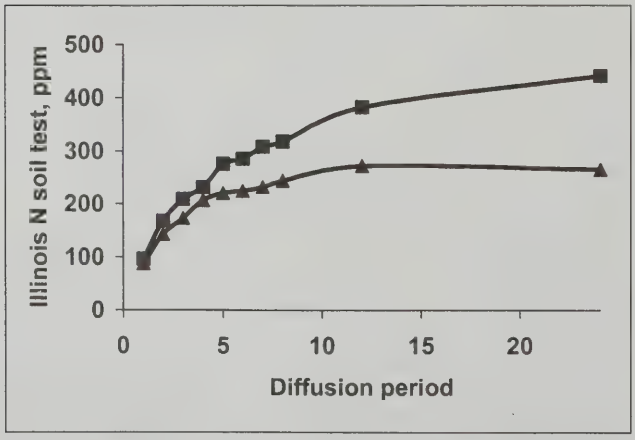



**Figure 4. Effect of heating time on liberation of amino sugar-N by the Illinois N soil test procedure.**

## Sampling depth

The N test described was developed using soil samples collected to a depth of 1 ft, but it should be equally suitable for samples collected to a depth of 6 or 7 inches in routine soil testing for pH, phosphorus (P) and potassium (K), because, unlike $NO_3^-$, amino sugars are not subject to extensive leaching. Support for this view is provided by Table 2, which summarizes data obtained for three different depths of a responsive and a nonresponsive soil. As expected, test values decreased when samples were collected to a greater depth, but in each case, a clear distinction was observed between the two soils. An important implication of Table 2 is that the critical value for detecting nonresponsive soils depends on sampling depth. In our work to date, this value appears to be approximately 240 ppm for 1-ft samples, whereas a value of approximately 300 ppm would probably be appropriate with 6- or 7-inch samples. Further research is required to ensure a sampling depth that provides the best possible correlation with crop response.

## Sampling time

If the soil test described measures a form of N that mineralizes readily, test values should decrease substantially during the growing season, which is exactly what was observed for soil samples collected from three rotations in the Morrow Plots during the 1998 growing season, beginning at emergence and concluding with fall tillage (Figure 5). Regardless of rotation, soil test values decreased after emergence, reaching a minimum at silking, when plant uptake of N would have been maximal. A subsequent increase in these values to near their original levels presumably reflects microbial assimilation of N during crop senescence and residue decomposition.

**Table 2. Effect of sampling depth on N test values for soils differing in N-fertilizer responsiveness.**

| | Sample Depth (inches) | Illinois N Soil Test (ppm) |
|---|---|---|
| Nonresponsive soils (2) | 0–6 | 339 |
| | 6–12 | 224 |
| | 12–24 | 130 |
| Responsive soils (2) | 0–6 | 160 |
| | 6–12 | 111 |
| | 12–24 | 78 |

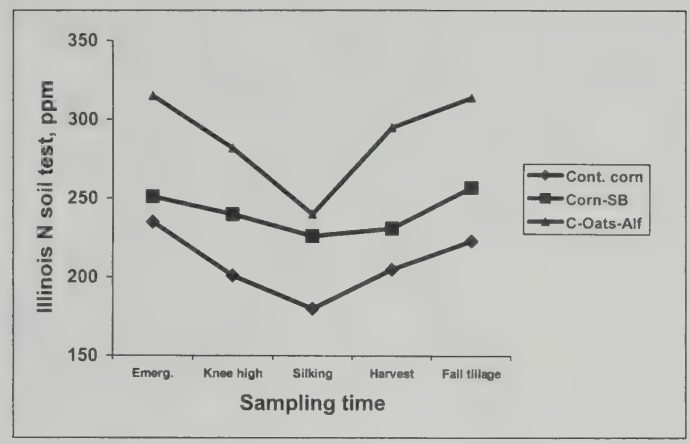



**Figure 5. Change in Illinois N soil test values over the growing season. Soil samples were collected in 1998 from the Morrow Plots, and were supplied by Dr. Michelle Wander.**

The data in Figure 5 suggest that soil sampling for the test described can be done before or after, but not during, the growing season, although further work is needed to confirm this critical issue. Also of interest is that Figure 5 shows a consistent difference between the three rotations studied, in that test values decreased according to previous cropping in the order, alfalfa > soybean > corn. The latter finding indicates the possibility that the soil test described may provide a quantitative basis for estimating N credits due to cropping.

### Spatial variability

A field of approximately 40 acres was sampled (to 6 inches) on a 1-acre grid in spring 2001 to characterize spatial variability in amino sugar-N. The results are summarized in Figure 6, which shows a range from 242 to 410 ppm, and a consistent pattern of variability relative to a barn and pasture area (not sampled) that occur in the existing farmstead. There has been no livestock production at this site for at least 17 yr, but before that time the field sampled had received regular applications of swine manure. Surprisingly, the soil test data in Figure 6 seem to indicate a residual effect of manuring. It is probably not coincidental that the highest test value was obtained for the area where the gate was once located. If the findings in Figure 6 are confirmed by additional studies, the soil test described may well become a useful basis for variable-rate application of N and also may revolutionize our understanding about the value of manure as a nutrient source.

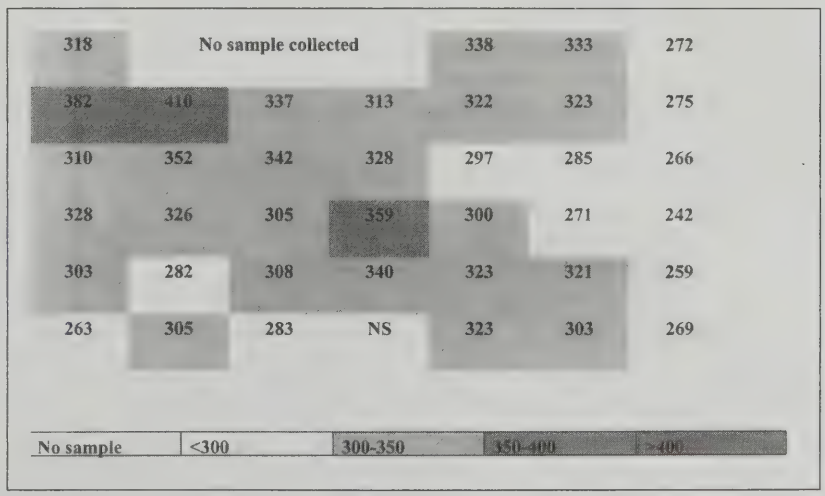



**Figure 6. Variation in Illinois N soil test across a 40-acre field.**

## SUMMARY

A simple soil test has been developed to estimate amino sugar-N, as a means of identifying sites where corn does not respond to N fertilization. This test avoids the need for acid hydrolysis or chemical extraction and is ideally suited for routine soil testing. Besides providing an unprecedented capability to detect nonresponsive sites, the test described may have important value for estimating how long such sites may remain nonresponsive and may provide a quantitative basis for N fertilizer recommendations. Work is in progress to calibrate the test for a wide range of soils and management practices, develop appropriate protocol for soil sampling and sample processing, and ascertain the effect of climatic conditions on the mineralization of amino sugar-N. Such information is a crucial prerequisite to successful applications on production fields.

## REFERENCES

Brown, H.M., R.G. Hoeft, and E.D. Nafziger. 1993. Evaluation of three N recommendation systems for corn yield and residual soil nitrate, in *1993 Illinois Fertilizer Conference Proceedings* (R.G. Hoeft ed) pp 43-49.

Bundy, L.G. and E.S. Malone. 1988. Effect of residual profile nitrate on corn response to applied nitrogen. *Soil Science Society of America Journal* 52: 1377-1383.

Bundy, L.G. and J.J. Meisinger. 1994. Nitrogen availability indices, in *Methods of Soil Analysis. Part 2. Biological Methods* (R.W. Weaver et al. eds) SSSA Book Ser. 5. Soil Science Society of America, Madison, WI, pp 951-984.

Dahnke, W.C. and G.V. Johnson. 1990. Testing soils for available nitrogen, in *Soil Testing and Plant Analysis, 3rd ed.* (R.L. Westerman et al. eds) SSSA Book Ser. 3. Soil Science Society of America, Madison, WI, pp 127-139.

Fox, R.H., G.W. Roth, K.V. Iversen, and W.P. Piekielek. 1989. Soil and tissue nitrate tests compared for predicting soil nitrogen availability to corn. *Agronomy Journal* 81: 971-974.

Harrington, P.D., E.D. Nafziger, and R.G. Hoeft. 1997. On-farm evaluation of variable-rate nitrogen fertilizer responses using farmer-owned equipment, in *1997 Illinois Fertilizer Conference Proceedings* (R.G. Hoeft ed), pp 57-64.

Khan, S.A., R.L. Mulvaney, and R.G. Hoeft. 2001. A simple soil test for detecting sites that are nonresponsive to nitrogen fertilization. *Soil Science Society of America Journal* (in press).

Meisinger, J.J., V.A. Bandel, J.S. Angle, B.E. O'Keefe, and C.M. Reynolds. 1992. Presidedress soil nitrate test evaluation in Maryland. *Soil Science Society of America Journal* 56: 1527-1532.

Mulvaney, R.L. and S.A. Khan. 2001. Diffusion methods to determine different forms of nitrogen in soil hydrolysates. *Soil Science Society of America Journal* 65: 1284-1292.

Mulvaney, R.L., S.A. Khan, R.G. Hoeft, and H.M. Brown. 2001. A soil organic nitrogen fraction that reduces the need for nitrogen fertilization. *Soil Science Society of America Journal* 65: 1164-1172.

Schmitt, M.A. and G.W. Randall. 1994. Developing a soil nitrogen test for improved recommendations for corn. *Journal of Production Agriculture* 7: 328-334.

# TMDLs and Other Alternatives

GEORGE F. CZAPAR

## INTRODUCTION

A total maximum daily load (TMDL) is the allowable amount of a single pollutant that a water body can receive from all contributing sources and still meet water quality standards or designated uses. In addition, implementation plans, recommended practices, and the cost of the program are still being examined.

More than 20,000 bodies of water across America have been identified as impaired. These waters include more than 300,000 river and shoreline miles and 5 million acres of lakes. The Environmental Protection Agency (EPA) estimates that more than 40,000 TMDLs must be established (U.S. EPA, 2001a). The cost of the program is still being evaluated, but it might exceed $4 billion dollars per year. The average cost of developing an individual TMDL is estimated to be $50,000, with a range of costs between $26,000 and $500,000 (U.S. EPA, 2001b).

In an effort to get public input and perspective about the TMDL program, the U.S. EPA conducted a series of five listening sessions around the country. The EPA will use the information received at these public listening sessions as it considers changes to the regulations, which govern the TMDL program (U.S. EPA, 2001c). Proposed modifications to the program are expected in mid-2002.

In 1998, the Illinois EPA identified 741 impaired waters that included 4,402 stream miles and 133,234 lake acres (IEPA, 2001a). The list contained a total of 2,863 impairments caused by 23 different pollutants. For a map of the watersheds and expected completion dates refer to the Illinois EPA Web site (IEPA, 2001b).

## ALTERNATIVES

Although the final TMDL rules may change, it seems very likely that any implementation strategies for improving water quality will include the use of best management practices (BMPs). Voluntary programs that adopt BMPs can be implemented today, without waiting for final wording of a federal document.

**Table 1. Illinois Watersheds under TMDL development for 2001 and 2002.**

| | Waterbody | County |
|---|---|---|
| 1 | Salt Creek | DuPage |
| 2 | East Branch DuPage River | DuPage |
| 3 | West Branch DuPage River | DuPage |
| 4 | Cedar Creek | Knox |
| 5 | Charleston Side Channel | Coles/ Cumberland |
| 6 | Little Wabash River | Shelby/ Effingham |
| 7 | Vandalia Lake | Fayette |
| 8 | Governor Bond Lake | Bond |
| 9 | East Fork Kaskaskia River | Marion |
| 10 | Fox River | Jasper/Richland |
| 11 | Casey Fork | Jefferson |
| 12 | Rayse Creek | Jefferson/Washington |
| 13 | Beaucoup Creek | Washington/Perry |
| 14 | Bonnie Creek | Perry |
| 15 | Little Muddy River | Jackson |
| 16 | Big Muddy River | Williamson |
| 17 | Big Muddy River | Jackson |
| 18 | Dutchman Creek | Johnson |

Source: Illinois EPA, 2001.

The Illinois Council on Best Management Practices (C-BMP) is a coalition of agribusiness, agricultural organizations, and University of Illinois Extension. Because nutrient management is an important water quality concern, proper fertilizer timing and application rates have been a C-BMP priority.

Similarly, the Illinois Department of Agriculture has formed a task force to address water quality issues related to agricultural nutrients. Underlying this effort is the recognition that state and federal resources are limited, and accurate targeting is critical to achieve water quality improvements. In other words, we want to make sure that we solve the right problem.

Other approaches involve the development of watershed resource planning committees before they are required. This approach gives the local residents a chance to prioritize their concerns, identify resources that are available, and secure resources that are needed.

Local involvement at the watershed level must be part of a successful program. Because most management practices need to be cost-effective before they are widely adopted, dealers and growers need to be involved early in the planning process. Addressing the impacts of agriculture on surface water continue to be one of the biggest challenges facing the industry.

## REFERENCES


Illinois Council on Best Management Practices (C-BMP). 2001. http://www.cbmp.uiuc.edu

Illinois Environmental Protection Agency, 2001a. Total Maximum Daily Loads - A Citizen's Guide. Bureau of Water. Springfield, IL.

Illinois Environmental Protection Agency, 2001b. http://www.epa.state.il.us/water/tmdl

U.S. Environmental Protection Agency (U.S. EPA). 2001a. Total maximum daily load (TMDL) program http://www.epa.gov/owow/tmdl

U.S. Environmental Protection Agency (U.S. EPA). 2001b. Total maximum daily load (TMDL) program. The National Costs of the Total Maximum Daily Load Program (Draft Report). http://www.epa.gov/owow/tmdl/coststudy/costfact.html

U.S. Environmental Protection Agency (U.S. EPA). 2001c. Total maximum daily load (TMDL) program. Public Meetings on the TMDL Program and Related Areas of the NPDES Program. http://www.epa.gov/owow/tmdl/meetings

# Effect of Tile Depth on Nitrate Transport from Tile Drainage Systems

**RICHARD COOKE, JEREMIAH NEHMELMAN, AND PRASANTA KALITA**

## ABSTRACT

In this report, we present results from a research project that was set up to test the hypothesis that the use of shallow drainage systems on poorly drained soils in Illinois will reduce the concentration of nitrate in tile effluent without having an adverse effect on crop yield. It involves the continuous monitoring of tile effluent from drainage tiles installed at different depths in a 40-acre (16-ha) field. The use of a single field reduces the confounding influence of soil, crop, size, and climate-major sources of external variability-thereby reducing the length of time required to draw conclusions from a study such as this that involves complex systems. Over the range of depths studied, 2 ft (0.6 m) to 4 ft (1.2 m), there appears to be a direct correlation between decreased tile flow and decreased tile depth. The same pattern holds true for nitrate mass loads. However, nitrate concentrations were not correlated with tile depth. These results are from 1 yr of study; thus, more data are required to validate the conclusions.

Nitrate-nitrogen (nitrate-N) in drinking water has been associated with several adverse health conditions. These conditions include blue baby syndrome, a condition in which nitrite interferes with the transport of oxygen in babies, and non-Hodgkins lymphoma (Nolan et al., 1997). High nitrate-N levels also have been linked to environmental problems such as hypoxia in the Gulf of Mexico.

It is generally believed that the main source of nitrate-N in water bodies is from agriculture. In central Illinois, for example, Mitchell et al. (2000) measured nitrate-N concentrations of 0 to 39 mg N/liter in tile effluent, and 0 to 15 mg N/liter in river water. These values were equated to nitrate-N losses from cropped fields ranging from 14 to 35 kg/ha/yr, appromimately 14 to 36% of the nitrogen applied, depending upon the management system.

Many studies have been initiated to develop practices to reduce nitrate-N levels leaving agricultural fields. In tiled fields, these practices include water table management and the use of inline subsurface bio-reactors. In this article, we present the results of yet another method, the use of shallow subsurface drainage systems.

### Water Table Management

With water table management, water that would normally be drained is detained in the field, causing the water table to rise. In turn, locations near the surface that contain soils high in organic matter become saturated and anaerobic. Theoretically, this condition results in increased denitrification.

Kalita and Kanwar (1993) postulated that the decreased nitrate-N concentrations discovered in their study were due to increased denitrification resulting from saturated conditions in the surface soil profile where organic matter is the greatest. McKenzie and Kuntz (1976) measured denitrification of 15N-labeled $NO^{-}_{3}$ to samples taken from various depths in silty clay loam soil. They found that significant levels of denitrification occurred after 32 d in the surface horizon (6.0% O.M.) but not in the deeper horizons where organic matter made up only 0.7% of the soil matter. Meek et al. (1970) also theorized that organic matter plays an important role in the denitrification process. They used columns to study the movement of as related to reduction-oxidation potential, dissolved oxygen, and soluble carbon and determined that dissolved carbon concentrations located 2.4 m below the soil surface decreased from approximately 40 mg/liter after the first irrigation to near zero after the last irrigation. They concluded that this change was most likely a result of consumption by denitrifying microorganisms.

Studies have repeatedly demonstrated that water table management practices are effective in reducing nitrate-N losses through tile drainage (Gilliam et al., 1979; Tan et

al., 1993; Drury et al., 1996). In North Carolina, Gilliam et al. (1979) discovered a reduction of 50% in nitrate-N loss for poorly drained soils by using controlled drainage systems. Drury et al. (1996) reported that a controlled drainage-subirrigation system reduced flow-weighted mean nitrate-N concentrations of tile drainage water by 25%. They found that annual nitrate-N loss was reduced by 43% with controlled drainage-subirrigation in place.

Subsurface Bio-reactors. Passive subsurface bio-reactors consist of subsurface chambers, filled with a carbon source, through which tile water is passed before flowing to a surface water body. Cooke et al. (2001) propose mixing the carbon source with gravel to provide structural support even when the carbon support has been depleted. The literature contains two references on the use of field-scale bio-reactors for treating tile effluent. Blowes et al. (1994) reported that small bio-reactors, used in-line on tile drainage systems, successfully reduced nitrate concentrations. However, the influent concentrations were much lower than typical tile nitrate concentrations from systems in the Midwest. Robertson et al. (2000) reported a reduction of 58% from a tile system with an average influent concentration of 4.8 mg/liter nitrate-N. In a companion experiment they observed an 80% reduction from a reactor underlying a septic system infiltration bed. The average influent concentration was 57 mg/liter nitrate-N.

Cooke et al. (2001) conducted a series of laboratory trials to evaluate the effect of carbon source and hydraulic retention time on the reduction of nitrate concentrations in bio-reactors. They developed performance curves for bio-reactors consisting of gravel mixed with corncobs or wood chips, with influent concentrations of up to 25 mg/liter nitrate-N. These curves show the relationship between retention time and nitrate reduction at temperatures ranging from 2 to 25°C. They then used these data to design field-scale systems that are currently being tested.

### Shallow Drainage Systems

In both the practices of water table management and the use of subsurface bio-reactors, the dominant nitrate removal mechanism is denitrification. Skaggs and Chescheir (1999) hypothesize that shallow drainage systems could have effects similar to those reported for water table management (controlled drainage) systems on nitrate-N loss via drainage water. However, unlike controlled drainage systems, shallow drainage does not allow for manual control of water table elevations. Thus, both hydraulic and chemical characteristics of flow need to be studied.

In shallow subsurface drainage systems, the laterals are placed shallower and closer together than is traditionally recommended for a given soil. One obvious benefit is that by decreasing the drainage depth, more water is available for plant uptake during dry years. During wet years excess water above the tiles will be removed quickly and efficiently, thus preventing crop yield reductions due to water stress. However, the major benefit of shallow drainage systems is that during the winter and early spring, when evapotranspiration is negligible, a larger anaerobic zone exists, which promotes the denitrification of excess nitrate-N below the tile drains. Skaggs and Chescheir (1999) surmise that much of the nitrate-N that would normally be leached through deep tiles between growing seasons will be converted to gaseous forms of nitrogen and released to the atmosphere.

Much research has been performed on the relationships between tile flow and drainage tile depth and spacing. One of the most well known studies on the relationships between tile flow and drainage tile depth and spacing was performed by Hoover and Schwab (1969). They used all combinations of 30-ft (9.1-m) and 60-ft (18.3-m) spacings and 2-ft (0.61-m) and 3-ft (0.91-m) depths of drains to determine the effects on drain discharge in a clay loam soil in Ohio. The tile lines were installed on a 54-acre (21.9-ha) tract partitioned into six fields. Using a 30-degree V-weir and stage recorder, tile flow was measured and water quality samples were collected. These researchers found that the ratio of tile discharge (per unit area) for 30-ft (9.1-m) spacing was in the range of 120 to 180% percent higher than that for 60-ft (18.3-m) spacing. This difference was statistically significant at the 1% level. They concluded that it was most probable that any given tile flow for the 30-ft (9.1-m) spacing would exceed that of the 60-ft (18.3-m) spacing. For tile depth, they determined that there were insignificant differences in tile flows associated with either the 2-ft (0.6-m) or 3-ft (0.9-m) deep drainage tiles.

Before the study conducted by Hoover and Schwab (1969), Goins (1956) performed a drainage depth and spacing study at the same location in Tiffin, OH. He recorded flow measurements for four combinations of tile at depths of 2 ft (0.6 m) and 3 ft (0.9 m) as well as spacings of 30 ft (9.1 m) and 60 ft (18.3 m). He determined that the tiles at shallow depths were characterized by faster rates of increase in tile flow. However, the flow decreased faster and consequently drained less total water from the soil.

Goins (1956) found that the difference in water removed by the various tile depths and spacing was highly significant, with the deep-narrow tile removing twice that removed by the shallow-wide tile. He went on to explain

**Table 1. Annual drainflow and flow weighted nitrate-N concentrations as influenced by drain spacing and field position (Kladivko et al., 1999).**

| | | Drain Spacing (m) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1988-1989 | | | 1989-1990 | | | 1990-1991 | | |
| Variable | Block | 5 | 10 | 20 | 5 | 10 | 20 | 5 | 10 | 20 |
| NO3-N (mg/liter) | 1 | 38.2 | 36.7 | 36.3 | 31.9 | 30.3 | 23.6 | 17.3 | 15.9 | 13.5 |
| NO3-N (mg/liter) | 2 | 28.8 | 28.8 | 31.4 | 23.0 | 26.0 | 25.4 | 14.2 | 13.9 | 16.0 |
| Drain flow (cm) | 1 | 26.2 | 12.9 | 10.8 | 13.0 | 6.1 | 7.4 | 27.9 | 11.6 | 10.4 |
| Drain flow (cm) | 2 | 36.6 | 30.8 | 19.6 | 22.3 | 17.4 | 16.8 | 28.4 | 23.6 | 19.2 |

that the shallow-narrow and deep-wide tiles were very similar in flow characteristics.

Kladivko et al. (1991) performed a similar experiment by using three drain spacings (5, 10, and 20 m) at the same depth on poorly drained Clermont silt loam soil at the Southeast Purdue Agricultural Center near Butlerville, IN. The surface soil was described as a light gray, low organic matter (1.3%) silt loam containing 22% sand, 66% silt, and 12% clay. According to King and Franzmeier (1981), a borderline fragipan existed in the B horizon, and a distinct paleosol surface was determined at 2- to 3-m depth. Corn was planted over the entire experimental area from 1984 to 1991 and fertilizer N (285 kg N ha-1) was injected as NH3 (with the nitrification inhibitor nitrapyrin) before planting in all years.

Kladivko et al. (1991) determined that the drains removed an amount of water equivalent to 6 to 27% of the total incident rainfall, depending on spacing and year. They also determined that water discharge per drain increased in relation to increased drain spacing. However, once the equivalent water depth of flow per unit area was taken into account, they determined that the depth of flow decreased as drain spacing increased.

In conjunction with hydraulic analysis, Kladivko et al. (1991, 1999) also characterized the effects that subsurface tile drainage spacing would have on nutrient loading. Beginning in April 1985, drain water samples were obtained manually by taking noncomposite point samples from the drainflow. In March 1986, automatic samplers (ISCO model 2700) were installed and were programmed to sample on a flow-proportional basis. These samples were then analyzed for nitrate concentrations.

Within a single cropping season, the most nitrate-N removed on a per area basis was from the 5-m spacing, whereas the least was from the 20-m spacing. Nitrate concentrations did not appear to vary consistently with daily drainflow volumes or with drain spacings but did show some seasonal and yearly variations. However, in conjunction with the flow data collected, it was determined that nutrient discharge varied with tile spacing (Table 2). In summary, Kladivko et al. (1991) determined that the total mass of nitrate removed was greatest for the 5-m spacing and least for the 20-m spacing. The same relationship was true for pesticides, other nutrients, sediment, and water removed on a per-area basis.

Kladivko et al. (1999) suggested that the magnitude of the differences associated with differing drain spacings needs to be assessed over several years due to flow changes that might occur as the new drainage system matured and as weather patterns changed. Because of this philosophy, continued monitoring of nitrate concentrations in tile flow were performed from 1989 through 1991. This time frame accounted for years 6 through 8 after drain installation.

Average annual nitrate-N losses through subsurface drains ranged between 14 and 105 kg/ha, varying with year, drain spacing, corn yield, and total drainflow (Table 1). According to Kladivko et al. (1999), the particularly high losses in 1988 to 1989 were probably due to low corn yields because of drought in the summer of 1988. These low yields, in turn, left higher amounts of residual NO3 in the soil profile.

**Table 2. Descriptive statistics for nitrate-N concentrations (mg N/liter) for each monitored tile line.**

| Tile Line | Number of Samples | Mean | Median | Std. Dev. |
|---|---|---|---|---|
| 4 ft | 113 | 13.68 | 13.61 | 1.88 |
| 3 ft(a) | 64 | 20.89 | 21.15 | 2.95 |
| 2 ft(a) | 33 | 14.71 | 14.11 | 3.26 |
| 3 ft(b) | 19 | 15.05 | 14.96 | 3.81 |
| 2 ft(b) | 16 | 15.43 | 15.16 | 3.25 |
| Combined 2 ft | 49 | 14.95 | 14.64 | 3.24 |
| Combined 3 ft | 83 | 19.55 | 20.77 | 3.99 |

The average annual nitrate-N losses over the 6-yr study, excluding 1988-1989, were 28, 36, and 51 kg/ha/yr for the 20-, 10-, and 5-m spacings, respectively. Kladivko et al. (1999) postulated that nitrate-N concentrations would be less if the drains were deeper, but this hypothesis was not experimentally verified.

Our study was initiated to further understand the effects that shallow drainage systems have on nitrate-N concentrations and nitrate-N mass loads in tile effluent for Drummer silt loam soils in east central Illinois. The specific objective of this study was to evaluate the performance of shallow subsurface drainage in Drummer silt loam with respect to hydrology and water quality.

## METHODS AND MATERIALS

The site chosen for this study is located in Douglas County, Illinois. This field is located in the central region of eastern Illinois within the lower portion of the Upper Embarras River Watershed. This report is based on experiments that were conducted at this site from spring 2000 through spring 2001. During this period, a corn and soybean rotation was in place, with soybean planted in 2000 and corn in 2001.

The monitoring site chosen was approximately 40 acres (16.2 ha) and consisted mainly of Drummer silty clay loam soil with a few pockets of Flanagan silt loam. The soil map for the site is shown in Figure 1. Drummer silty clay loam, the dominant soil type, is described as being a deep, poorly drained soil that occupies large, nearly level, irregularly shaped areas and medium-sized, long narrow areas where the surrounding topography is more sloping. Due to the nearly level low-lying areas associated with this site, as well as the deep, poorly drained soils, long-term ponding was found during wet periods.

A topographic map of the field is shown in Figure 2. The coordinates and elevation of a point close to the center of the field were arbitrarily set as {5000 ft, 5000 ft} ({1524 m, 1524 m}) and 100 ft (30.5 m), respectively. As can be observed, the field slopes downward towards the southwest edge with an approximate slope of 0.3%.

Before this study, the field did not have artificial drainage. The drainage system was installed during fall 1999. The drainage system was designed not only to study the effect of depth on water quantity and quality but also to provide adequate drainage for the field. Thus, the shallower drains were placed closer together than the deeper drains.

The layout of the drainage system is shown in Figure 3. Two monitored subsurface tile lines were installed 2 ft (0.6 m) below the surface. Two others were installed 3 ft

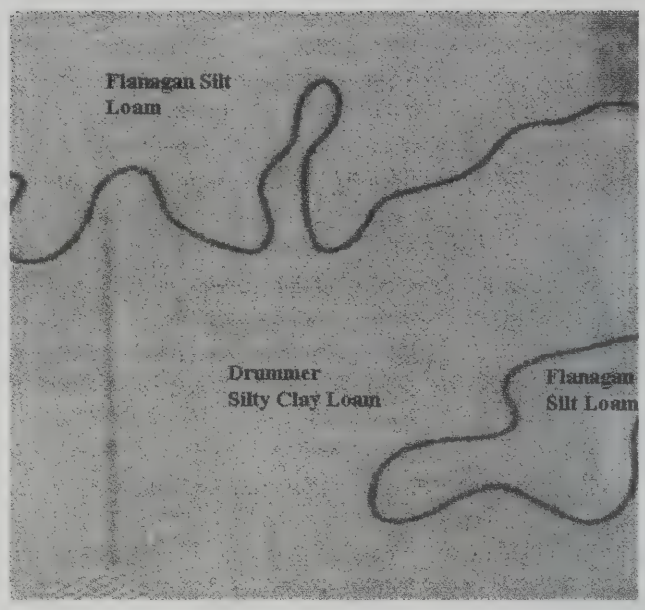



**Figure 1. Soil map of research site.**

(0.9 m) below the surface, and a fifth monitored tile was installed 4 ft (1.2 m) below the surface. With the exception of the deepest tile, each of these monitored lines was bordered on either side by a buffer tile placed at the same depth. Because of space constraints, the deepest monitored tile had only one buffer tile at the same depth. The buffer tiles were spaced 50 ft (15.2 m) on either side of the 2-ft-deep monitored tiles and 100 ft (30.5 m) on either side of the other monitored tiles. The buffer tiles

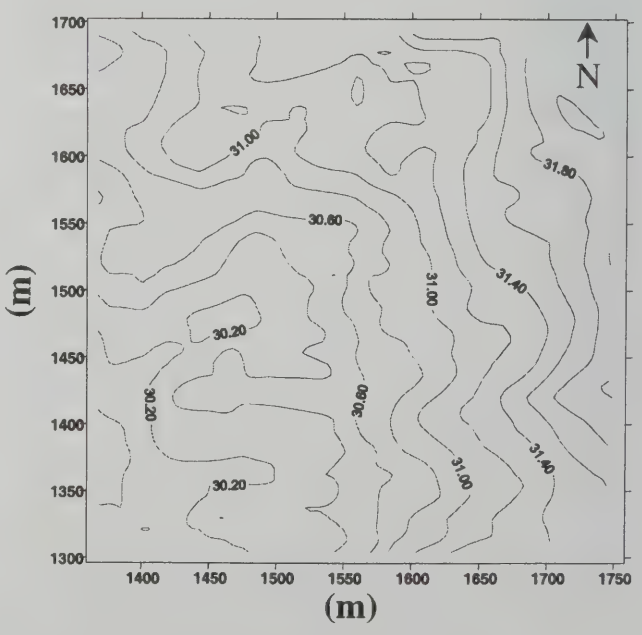



**Figure 2. Topographic map of reserch site.**

were installed to hydraulically isolate each of the monitored tiles.

All of the laterals were 4-in.- (10.2-cm)-diameter corrugated plastic tubing and were installed over the entire length of the field, parallel to the east and west edges. The two tile lines at 4 ft (1.2 m) deep were on average 250 ft (76.2 m) shorter than the other tile lines. All the laterals emptied into a 10-in.- (25.4-cm)-diameter tile main installed along the south edge of the field. This tile main entered another tile line at the southwest corner of the site.

Each monitored tile line was intercepted by a manhole with a 6-in.- (15.2-cm)-Palmer-Bowlus flume, a sensor to measure flow depth in the flume, a data logger, and an automatic sampler. The data logger was used to convert the depth measurements into flow rates based on the rating curve for the flume and to trigger the sampler after predetermined flow volume increments.

Once the water samples were collected, they were preserved and refrigerated at 4(C until analyzed for nitrate-N and phosphorus concentrations by using standard methods. These measured concentrations, along with the corresponding tile discharges, were used to determine mass loads for the chemical constituents.

Climate data, namely, humidity, air temperature, rainfall, wind velocity, and soil temperature, were all recorded hourly with a Global Water weather station. Rainfall also was measured independently using a HOBO tipping bucket rain gauge and datalogger.

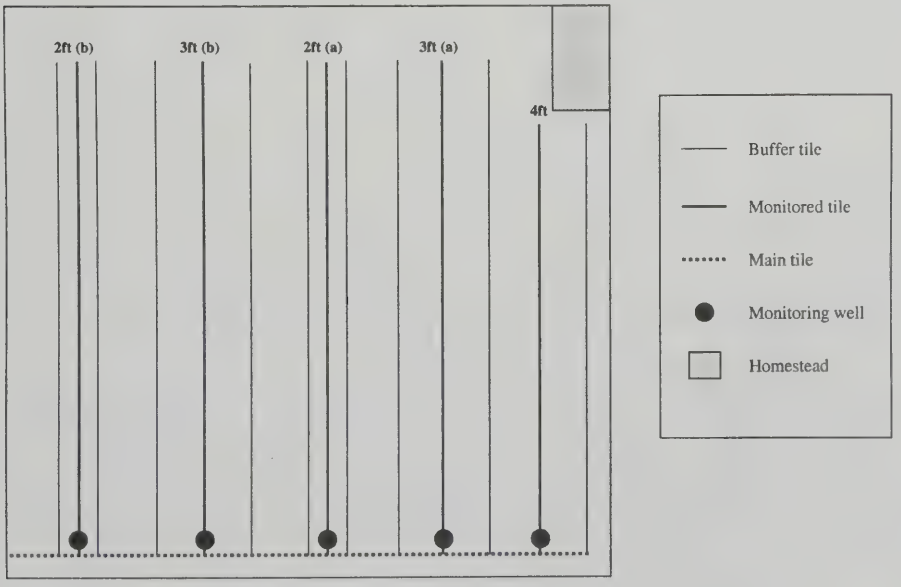



**Figure 3. Layout of drainage system.**

The univariate procedure in SAS (release 8.12) was used to fit probability distribution functions to the concentration data. Nonparametric statistical procedures, specifically the Kruskal-Wallis and Wilcoxon tests, also were used with the nitrate-N concentration data. The Kruskal-Wallis test is used when more than two populations are to be compared and the data are not parametric (Longnecker and Ott, 2001). This test compares sample means based on the sum of their ranks. With this test, the sample numbers for the treatments do not have to be equivalent (Hollander and Wolfe, 1973). When comparing only two treatments, the Wilcoxon Rank Sum procedure was used. In each case, the independent variable was the tile station and the dependent variable was either concentration, mass of nutrient, or discharge.

Based on these procedures, comparisons were performed between each of the tile lines to determine the influence of tile depth on flow and nitrate transport. The results of these analyses are presented in the next section.

## RESULTS AND DISCUSSIONS

The results presented in this article are based on an analysis of the data collected between April 2000 and May 2001. It should be stressed that 1 yr is not an adequate duration to determine the long-term effects associated with these differing subsurface tile installation designs. The conclusions drawn in this report can only be defined as preliminary findings and should not be regarded as conclusive evidence for or against the use of shallow depth drainage systems to decrease nitrate-N concentrations, subsurface tile flow, or mass loadings of nitrate-N.

Observed daily volumetric flows for each monitored tile lines are shown in Figure 4. There were many periods, such as between July 1, 2000, and November 1, 2000, when no flow occurred in any of the five monitored tile lines. Thus, the tile flow data could easily be separated into discrete events. Some of these events were in direct response to rainfall (Figures 5-7), whereas most of the events that occurred during the winter (Figure 8) were influenced by freeze/thaw cycles and, possibly, regional groundwater movement. In addition the

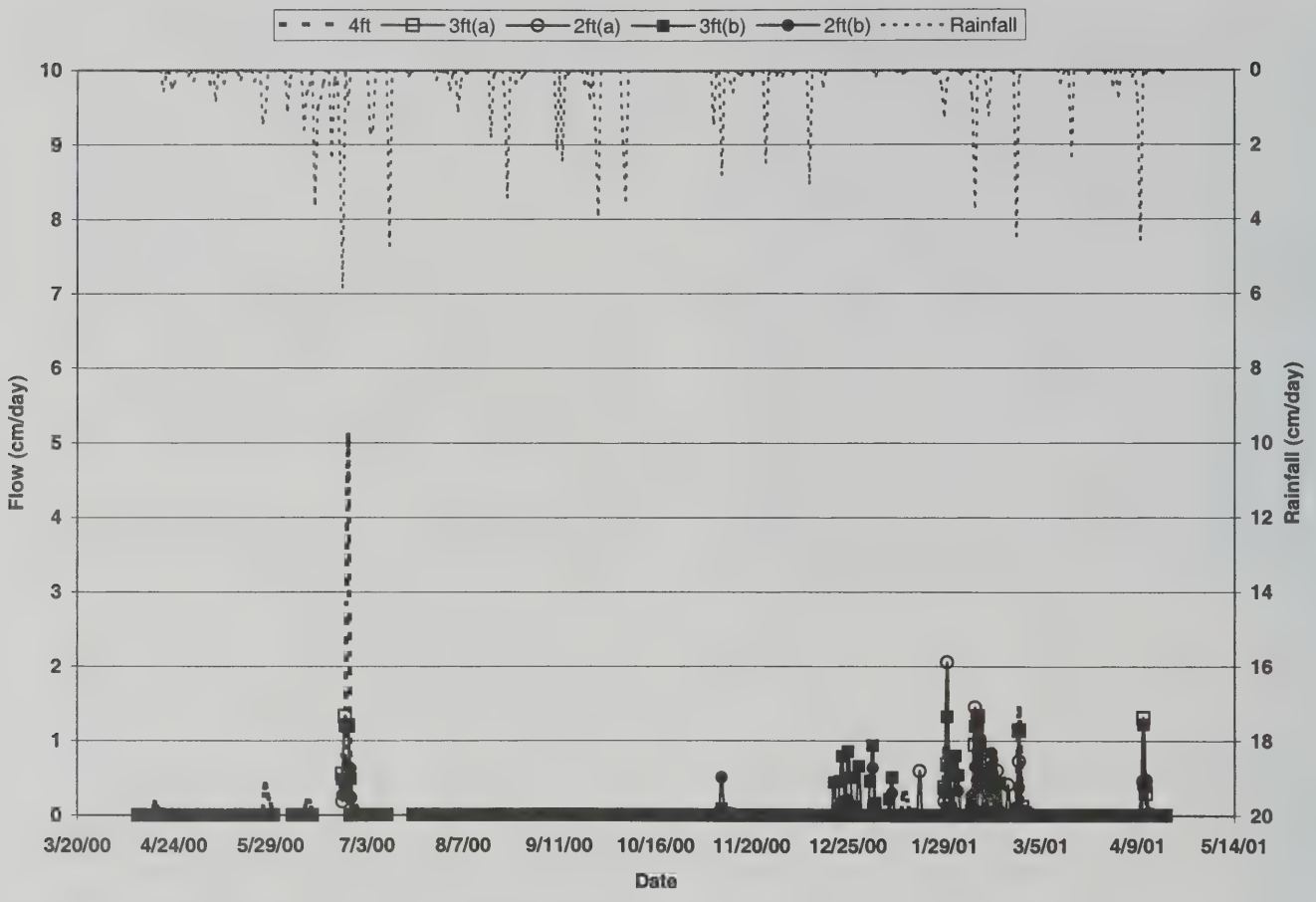



Figure 4. Rainfall and tile flow over monitored period.

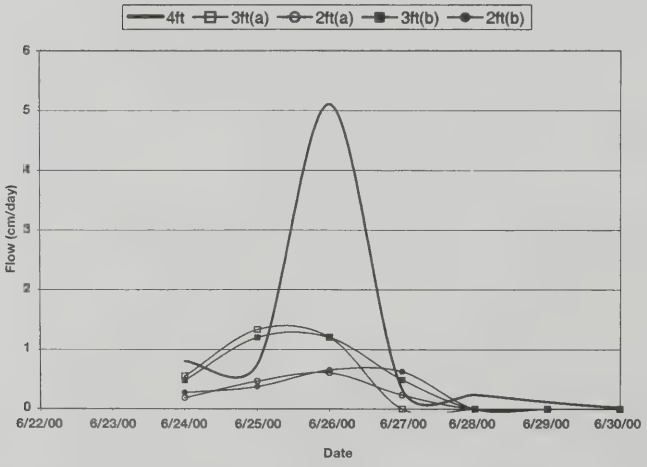



Figure 5. Tile flow hydrographs for June (2000) event.

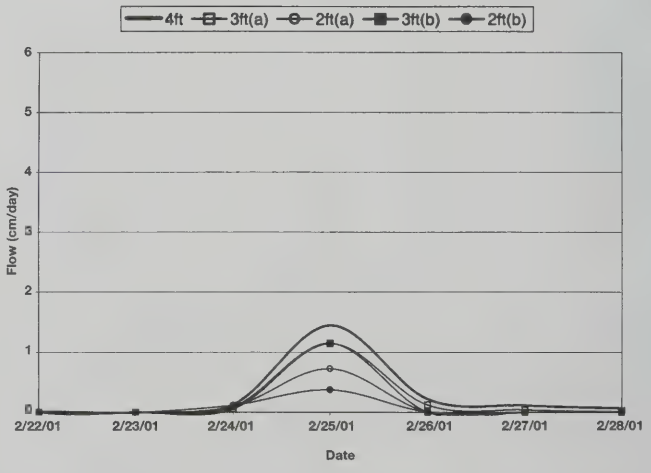



Figure 6. Tile flow hydrographs for February (2001) event.

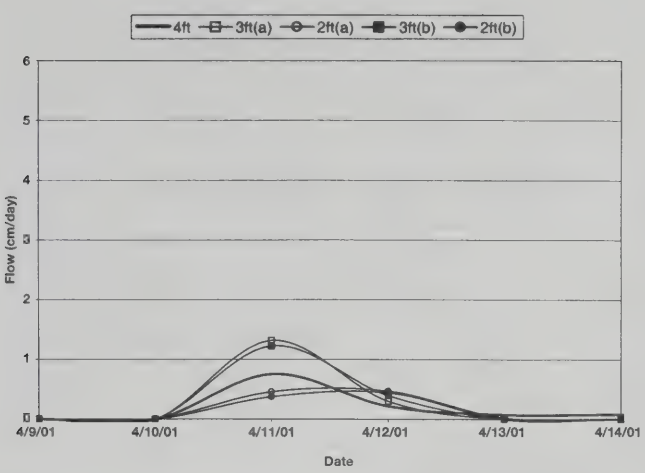



**Figure 7. Tile flow hydrographs for April (2001) event.**

blowing and drifting of snow confounded the analysis of the winter events. Therefore, the flow events that were in direct response to rainfall and the winter events were analyzed separately.

## Flow

In general, peak tile flows decreased with decreasing tile depth. However, for the event in April 2001, the peak tile flow associated with the 4-ft- (1.2-m)-deep tile line was less than that associated with each of the 3 ft (0.9 m) tile lines. This deviation may be the result of many factors, including, but not limited to, antecedent moisture conditions, rainfall intensity, and tillage.

In all cases, however, flow volume increased with increasing tile depth. Cumulative flow volumes are shown in Figure 9. Average cumulative tile flow for the 2-ft- (0.6-m)-deep tiles was 43% less than that for the 3-ft (0.9-m) tiles. Average cumulative flows for the 3-ft (0.9-m) tile was 33% less than that of the 4-ft (1.2-m) tile for the same period.

By using linear regression analysis, cumulative flows over discrete flow events were compared to determine correlation between tile depth and tile flow. On average, tile flows originating from the monitored tile lines at a 3-ft (0.9-m) depth were 38.2% less than those from the tile line at 4 ft (1.2 m). The monitored tile lines at a depth of 2 ft (0.6 m) were estimated to release 44.3% less flow than the tile line installed at 4 ft (1.2 m).

Based on the flow comparative analyses for the observed period, we concluded that an increase in the quantity of tile flow is directly correlated with an increase in tile depth. It appears, however, that the differences associated with the overall cumulative flow were much greater than those associated with cumulative flow comparisons for discrete events. Because of these deviations, we concluded that there is dependence on factors that are external to this study. Further research is needed to identify these factors.

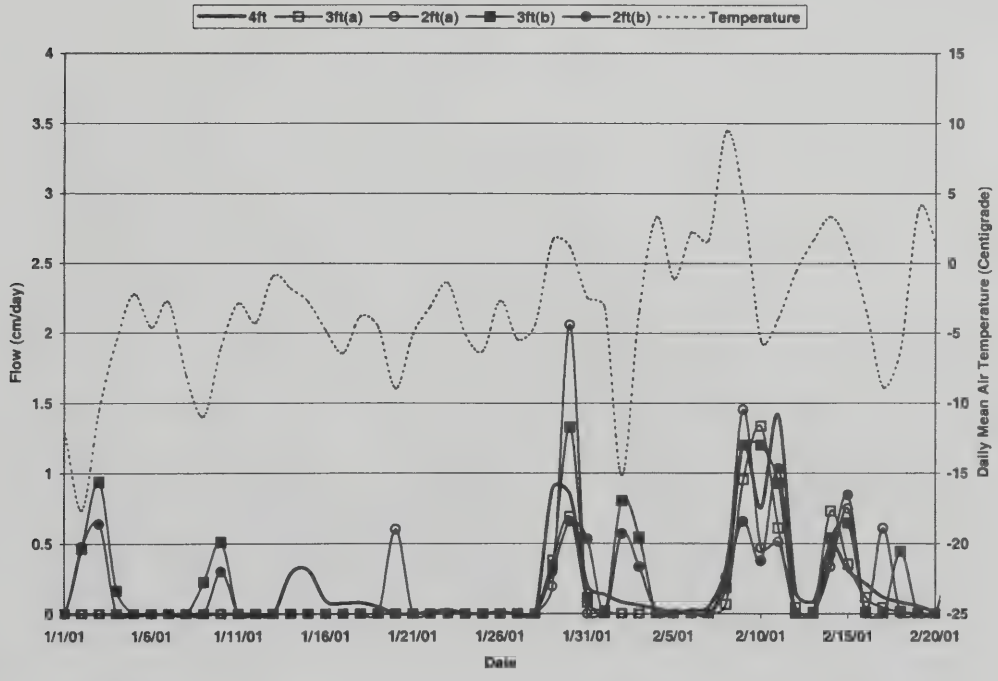



**Figure 8. Tile flow hydrographs for non rainfall-driven winter (2001) events.**

## Nitrate-N Concentrations

Nitrate-N concentrations were determined for each of the samples extracted from the tile flow. These concentrations are shown in Figure 10. We observed seasonal variations in the concentrations. Between March 2000 and July 2000, the concentrations decreased significantly for all tile except for the 3-ft(a) tile line. Tile line 3 ft(a) passes through a sand lens that has properties that are different to those of the

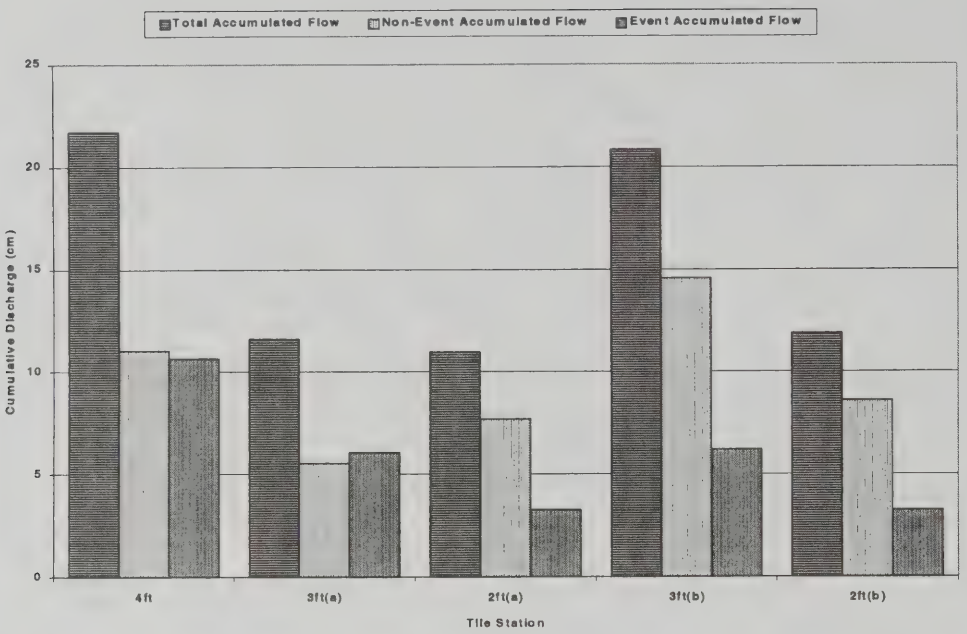



**Figure 9. Cumulative discharge histograms (April, 2000–May, 2001).**

dominant soils, and this could explain the drastic difference in nitrate-N concentrations.

By fall 2000, nitrate-N concentrations again began to rise. These increases are most likely due to the application of anhydrous-ammonia during October 2000. It also appears that during this time, tile line 3 ft(a) had similar concentrations as the other four tile lines.

Using the Kruskal-Wallis and Wilcoxon statistical tests, it was determined that nitrate-N concentrations for tile line 3 ft(a) were significantly different compared with nitrate-N concentrations for any of the other four tile lines (Tables 2 and 3). Furthermore, the concentrations for tile lines 4 ft, 3 ft(b), 2 ft(a), and 2 ft(b) were statistically similar. Thus, no correlation can be determined between tile depth and nitrate-N concentrations.

## Nitrate-N Mass Loads

Nitrate-N mass loads were evaluated using both the tile flow data and the nitrate-N concentration data. Cumulative mass loads are shown in Figure 11. The tile lines at 2 ft (0.6 m) in depth contributed significantly less nitrate-N mass loads than the tiles at 3 ft (0.9 m) or the tile line at 4 ft (1.2 m). The average reduction for the 3-ft (0.9-m) tile lines, compared with the tile line at 4 ft (1.2 m), was 22%. The average mass load from the 2-ft (0.6-m) tiles was 51% less than that for the tile line at 4 ft (1.2 m).

Using regression analysis results for the discrete flow events, an average reduction of 27% was effected by installing tile lines at 3 ft (0.9 m) as opposed to 4 ft (1.2 m). Installing tile lines at 2 ft (0.6 m) rather than 4 ft (1.2 m) will result in a reduction of nitrate-N mass loads of 51%.

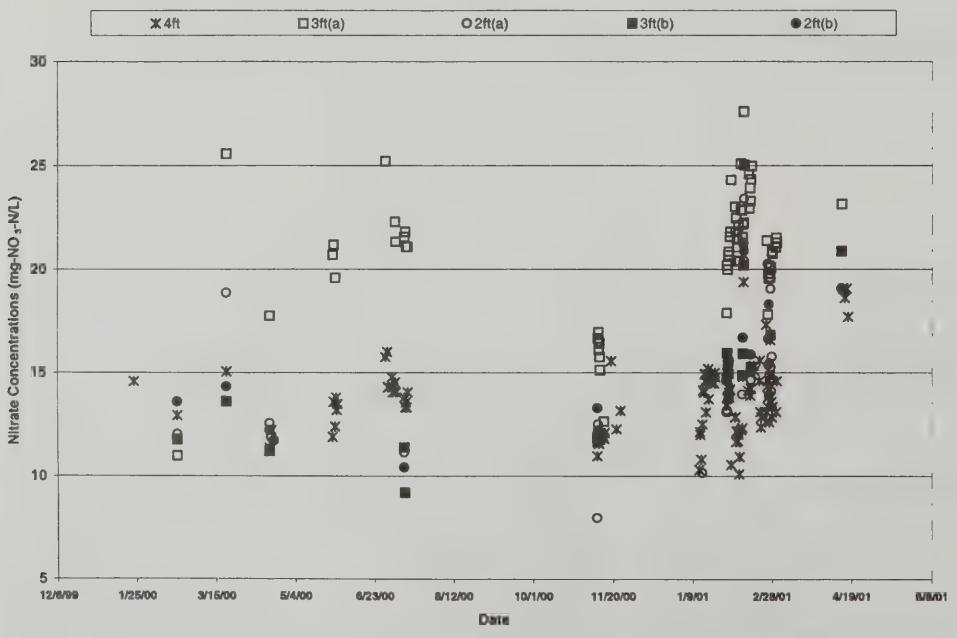



**Figure 10. Nitrate concentration in tile effluent (January 2000 to May 2001).**

**Table 3. Results of Kruskal-Wallis tests for differences in nitrate-N concentrations (mg N/liter) for each monitored tile line.**[a]

| | | | | | |
|---|---|---|---|---|---|
| **Significance level = 0.05** | | | | | |
| Individual Tiles: | 3 ft(a) | 2 ft(b) | 3 ft(b) | 2ft(a) | 4 ft |
| Combined Tiles: | 3 ft combined | | 2 ft combined | | 4 ft |
| **Significance level = 0.025** | | | | | |
| Individual Tiles: | 3ft(a) | 2ft(b) | 3ft(b) | 2ft(a) | 4ft |
| Combined Tiles: | 3ft combined | | 2ft combined | | 4ft |
| Decreasing N Concentrations —> | | | | | |

[a] Values connected by the same bar are not significantly different.

Based on these results, it can be concluded that there is a direct correlation between the depth of installation and the amount of nitrate-N mass load determined for this period at this specific site.

## SUMMARY

Over the range of depths studied, 2 ft (0.6 m) to 4 ft (1.2 m), there appears to be a direct correlation between decreased tile flow and decreased tile depth. The same pattern holds true for nitrate mass loads. However, nitrate concentrations were not correlated with tile depth. These results are from only 1 yr of study. More data are required to validate these conclusions.

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## REFERENCES

Blowes, D.W., W.D. Robertson, J.D. Ptacek, and C. Merkley. 1994. Removal of agricultural nitrate from tile drainage effluent water using inline bio-reactors. *Journal of Contaminant Hydrology* 15: 207-221.

Cooke, R.A., A.M. Doheny, and M.C. Hirschi. 2001. Bioreactors for edge-of-field treatment of tile outflow. *ASAE Paper No. 01-2018*. St. Joseph, MI.

Drury, C.F., C.S. Tan, J.D. Gaynor, T.O. Oloya, and T.W. Welacky. 1996. Influence of controlled drainage-subirrigation on surface and tile drainage nitrate loss. *Journal of Environmental Quality* 25: 317-324.

Gilliam, J.W., R.W. Skaggs, and S.B. Weed. 1979. Drainage control to diminish nitrate loss from agricultural fields. *Journal of Environmental Quality* 8: 137-142.

Goins, T. 1956. Tile flow characteristics. *Transactions of the ASAE*. 37: 3032, 35.

Hollander, M. and D.A. Wolfe. 1973. *Nonparametric Statistical Methods*. John Wiley & Sons, Inc., New York.

Hoover, J.R. and G.O. Schwab. 1969. Effect of tile depth, spacing, and cropping practices on drain discharge. *Transactions of the ASAE* 12: 150-152.

Kalita, P.K. and R.S. Kanwar. 1993. Effect of water-table management practices on the transport of nitrate-N to shallow groundwater. *Transactions of the ASAE* 36: 413-422.

King, J.J. and D.P. Franzmeier. 1981. *Morphology, hydrology, and management of Clermont soils*. Indiana Academy of Science 90: 416-422.

Kladivko, E.J., J. Grochulska, R.F. Turco, G.E. Van Scoyoc, and J.D. Eigel. 1999. Pesticide and nitrate transport into subsurface tile drains of different spacings. *Journal of Environmental Quality* 28: 997-1004.

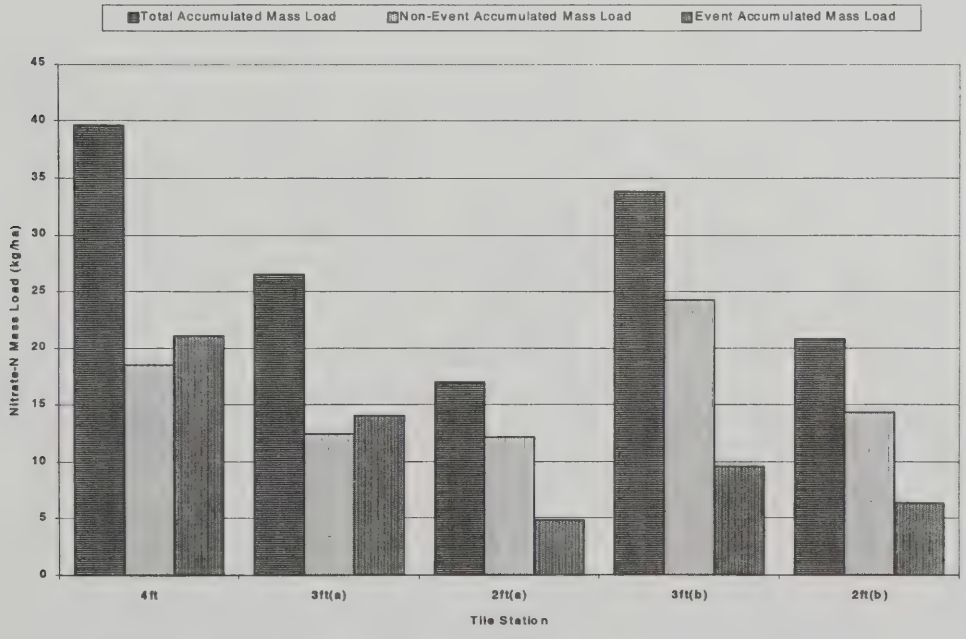



**Figure 11. Histograms of cumulative nitrate-N mass loads (April, 2000 to May, 2001).**

Kladivko, E.J., G.E. Van Scoyoc, E.J. Monke, K.M. Oates, and W. Pask. 1991. Pesticide and nutrient movement into subsurface tile drains on a silt loam in Indiana. *Journal of Environmental Quality* 20: 264-270.

Longnecker, M. and R.L. Ott. 2001. *An Introduction to Statistical Methods and Data Analysis, 5th ed.* Thompson Learning, Pacific Grove, CA.

McKenzie and Kuntz. 1976. As cited in Baker, J.L. and H.P. Johnson. 1976. Impact of subsurface drainage on water quality, pp. 91-98. Proc. 3rd Nat. Drainage Symp. *ASAE Publication 1-77*, Chicago, IL. December. St. Joseph, MI.

Meek et al. 1970. As cited in Baker, J.L. and H.P. Johnson. 1977. Impact of subsurface drainage on water quality. *Proc. 3rd Nat. Drainage Symp*. St. Joseph, MI.

Mitchell, J.K., G.F. McIsaac, S.E. Walker, and M.C. Hirschi. 2000. *Nitrate in river and subsurface drainage flows from an East Central Illinois watershed*. Transactions of the ASAE. 43: 337-342.

Nolan, B.T., B.C. Ruddy, K.J. Hitt, and D.R. Helsel. 1997. Risk of nitrate in groundwaters of the United States - A national perspective. *Environmental Science and Technology* 31: 2229-2236.

Robertson, W.D., D.W. Blowes, C.J. Ptacek and J.A. Cherry. 2000. Long-term performance of in-situ reactive barriers for nitrate remediation. *Groundwater* 38: 689-695.

Skaggs, R.W. and G.M. Chescheir. 1999. Effect of subsurface drain depth on nitrogen losses from drained lands. *ASAE Paper No. 99-2086*. St. Joseph, MI.

Tan, C.S., C.F. Drury, J.D. Gaynor, and T.W. Welacky. 1993. Integrated soil, crop and water management system to abate herbicide and nitrate contamination of the Great Lakes. *Water Science Technology* 28: 497-507.

# SOILS and WATER: On-Farm Trials Results

**EMERSON NAFZIGER, ROBERT HOEFT AND ALAN GULSO**

The Illinois Department of Agriculture (IDOA) has recently been active in initiating projects to highlight the effects of cropping practices on the environment. They have established two collaborative projects with scientists in the Department of Crop Sciences at the University of Illinois in the past 2 yr. To draw attention to these activities, field plots in both projects are located for high visibility and are announced by large signs, usually alongside interstate highways. These projects are described herein, with some preliminary results.

## SOILS

Tillage systems used for crop production in Illinois are constantly changing as new equipment and new technologies emerge. In 2000, the IDOA initiated a project entitled Save Our Illinois Soils (SOILS), with the goal of comparing strip-till, no-till, and mulch-till (chisel plow) tillage systems for corn production in farmer fields in Illinois. Personnel from the IDA identified farmers who had fields near highways, and who were willing to conduct comparisons of these tillage systems in their fields. Field-length strips were laid out in fall 1999, with two replications (strips) of each tillage system. In the spring, University of Illinois personnel placed temperature probes in the row to measure differences in soil temperature. They also measured residue cover after planting and plant height after several weeks of growth, to document effects of tillage. Yields were taken with yield monitors or weigh wagons.

Table 1 gives residue cover, accumulated soil growing degree days (GDD, base 50°F) 4 wk after planting, emerged plant counts, and plant height 5 wk after planting for a representative site in east central Illinois. The effect of tillage on soils and plant growth in spring 2000 was minimal. Soils were relatively warm and dry regardless of tillage type, and even though no-till soils had more residue cover and slightly lower temperatures, stands and growth were about the same for all three systems. These findings were typical of those at most SOILS locations in 2000. Not including two southern Illinois locations where excessively wet soils produced unusable results, yields from the three systems averaged across locations were as follows: no-till, 158.5 bu/acre; strip-till, 158.5; and chisel plow, 162.3. Although yield data from 2001 are not yet available, the spring weather was again relatively warm and dry, and we saw minimal effects of tillage on plant establishment and early growth.

## WATER

In 2001, the IDOA initiated another project, designed to demonstrate and quantify the response of corn to nitrogen fertilizer rate, in an attempt to educate producers and dealers about optimal nitrogen (N) rates and the economic and environmental consequences of exceeding those rates. This project was given the acronym WATER, for What Are The Economic Rates? Rates of 0, 50, 100, 150, and 200 lb N/acre were applied using regular N application equipment to field-length strips that were 20 to 60 feet in width. Nine sites were established. Yield results are discussed. It is anticipated that this project will be expanded in 2002 to include more locations.

**Table 1. Comparison of tillage systems for corn production in farmer fields in Illinois.**

| Tillage | Residue cover (%) | Soil GDD | Plants/acre | Plant height (in.) |
|---|---|---|---|---|
| Chisel plow | 63 | 525 | 25,129 | 29.5 |
| Strip-till | 74 | 491 | 26,082 | 32.4 |
| No-till | 83 | 479 | 26,883 | 28.7 |

# Biotechnology: The Future for Corn

**RANDY KROTZ**

# Biotechnology Patent Issues: An Industry Perspective

JAMES R. SHEARL

Golden Harvest Seeds, Inc., is the fourth largest seed company in terms of U.S. corn seed sales and the sixth largest in soybean seed sales. This company has a substantial commitment to biotechnology (or biotech) seeds, and considers them one of the best new tools to offer customers to position them to be more efficient and profitable. Thus, Golden Harvest Seeds, Inc., has a commitment to protect the privileges of patenting seeds and biotechnology traits. The following are comments regarding the importance of patenting.

Monsanto recently reported that 74% of the newly purchased soybean in the United States contains an enhanced trait. At Golden Harvest Seeds, Inc., many sales areas are approaching 90% use of enhanced soybean traits. The impact of improvements in soybean production as the result of biotechnology traits has been dramatic. In addition to companies of similar size as Golden Harvest Seeds, Inc., small seed companies have experienced impressive growth since the introduction of value added seeds; trait suppliers have increased the release of new and better germplasms and research and development investment has increased substantially. Dealer profitability continues to decline and new seed products offer a continuing opportunity to sell higher value goods to grower customers who themselves have faced harsh markets and increasing global competition. Additionally, as patents begin to expire in the future, such traits will be available to the public even as new and better choices are developed.

## Government View: Regulations, Monitoring, Identity Preservation and Traceability, and Public Research

The responsible governing of a diverse people with diverse views and perspectives is always a challenge. Biotechnology holds the potential to improve the lives of practically every person on this earth whether from improved diet or in the form of cures or treatments for terminal diseases. Balanced against this potential is the impact of "change" on many groups of people who have built businesses, lifestyles, and comfort zones around the very challenges and barriers that could be overcome by advances in technology and science. Undefined calls for "regulations," "safety protocols," and "limitations on use" will likely dominate the next few years as society more deeply explores and accepts the benefits of biotechnology. As new products emerge, new opportunities to manage and benefit from these products also will begin to form. Monitoring of high-value production will require skilled people with a talent for quality control; specialty markets may command source or origination tracking and traceability of production may play increasingly important roles in marketing of certain crops. Public research will be expected to compete with well-funded private creation efforts, and cooperation between public and private concerns may prove to be the best solution in the effort to deliver safer, more abundant food to a growing population. Public research continues to turn out new science but it is usually private capital that drives that science through development and implementation and use through demand generation and marketing. In 1994, total public research for agricultural biotechnology was $2.2 billion, whereas private research topped $4 billion. By 1999, private research investment eclipsed public funding, moving ahead of the $10 billion mark. Public research funding remained flat. This situation is not likely to change in the near future given the enormous risk associated with biotechnology capital investment. The spending of public money is closely scrutinized and the risks associated with the development and marketing of biotech products does not invite public expenditure. Private investors can spread this risk across a number of investments and hedge the overall package of development decisions one against another. If public invention is to enjoy full implementation, partnerships with private

investment capital will likely play an increasingly important role.

### Consumer View: Reduction in Use of Pesticides, Groundwater Contamination, Abundant Food, and Third World Economic Development

Consumers want safe and abundant food at convenient locations and at fair prices. Research has shown that U.S. consumers recognize the value of biotechnology for many reasons, including the reduction in the use of pesticides required to manage biotech food production. Other benefits include the potential for cleaner groundwater made possible from both the reduction in pesticide use and from the increased use of conservation tillage. As our world population grows, the demands on our collective ability to produce food for a population that is growing in affluency will be answered, in part, through the biotech development of crops that can overcome limitations of soil, water, and other environmental barriers to make food production more suitable to regions with a declining ability to produce. Consumer benefits include the presence of fewer microtoxins in corn, enhanced nutritional value, cleaner water, and enhanced wildlife management. These benefits must be communicated to consumers as we work together to educate against a growing attempt to create unwarranted fear in food safety.

### Farmer View: Increasing Global Competitiveness versus International Law, Including Protectionism and Intellectual Property Protection

Global commodity markets and governmental commodity support policy is facing increasing challenge in the world free trade arena. Argentine farmers curse U.S. politics for subsidizing commodity crop production and U.S. farmers voice frustration with Argentine intellectual property law deficiencies. Buyers of commodities enter the market without preference for source or origination of their respective commodities and price remains the major term of sale in a self-perpetuating "buyer's market." Biotechnology provides the most promising opportunity for escape from this hopeless system through the advent of specialty and value added crops, which may be "grown to order" or grown under contract with terms that spread risk and reward in a more equitable manner. These high-value products will likely require more intense and complex management that is most readily available form North American farmers who enjoy a highly developed and continuously maintained transportation system and the most advanced education and support system for production agriculture in the world. Farmers who reside in states with unlimited freedom to contract will be in the best position to take advantage of these opportunities as they begin to develop. The farmer's freedom to contract and otherwise operate will be increasingly more important in the future of U.S. agriculture. The National Center for Food and Agriculture Policy states that the introduction of Roundup Ready soybean has resulted in an annual cost savings of $216 million in weed control and $19 million fewer soybean herbicide applications each year.

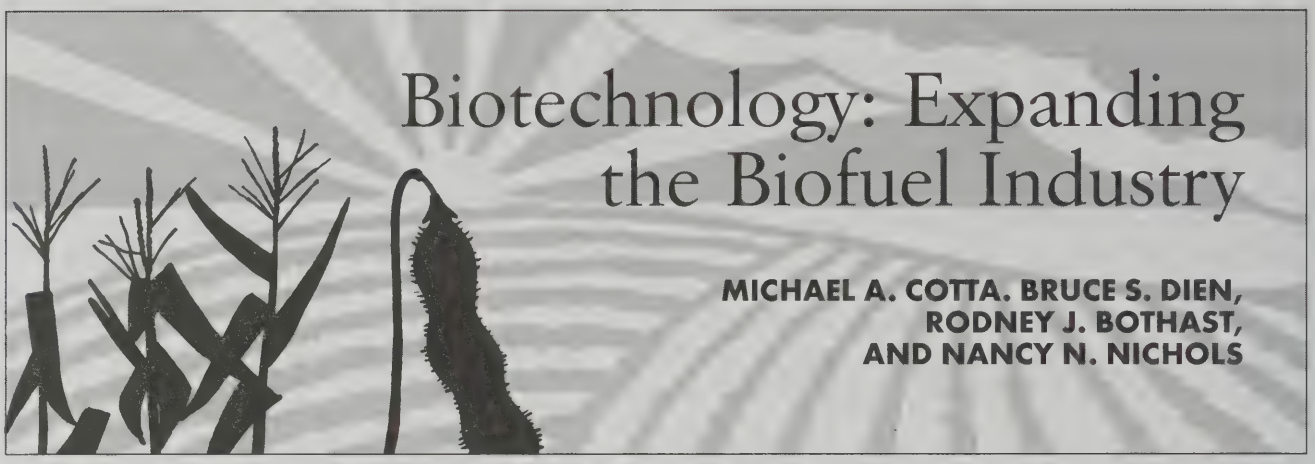
### Value Capture: Motivation for Initial and Continuing Investment Assurance of Return on Investment (Risk versus Opportunity Returns)

Private research and development continues to bring some of the most valuable and desirable advances in production agriculture. These private concerns have both practical and legal obligations to implement responsible value capture business models. These limitations will require change and acceptance of concepts never before considered or understood. Like most advances, there will be opportunities and challenges and producers will cast the ultimate vote by their decision to adopt and return to the new products that find their way into the market. Perhaps the most important tool to enable the maximum number of growers to share in the value created by private research and development is the concept of licensing. Licensing is a very powerful tool that allows private ownership to share the benefits of a newly developed product and simultaneously provide for the protection of the intellectual property required to delivery that product to the market. As the biotech industry develops, the value of what is created will be front-heavy on costs and very inexpensive to replicate once the product is produced. It takes hundreds of millions of dollars to develop and deliver a new biotech product to market, and once it is in the market it is often very easy to copy. Companies will only be willing to invest high-risk capital if they can be protected from loss of that asset through theft. If licensing is limited and protection of intellectual property ignored, the value of the asset will sharply decline and responsible companies will exit from or alter the business in a way that cannot include sharing of the value with others. Federal law recognizes this need and provides for numerous levels of protection. Through U.S. Patent Law, a trait can be protected from unauthorized use for more than 17 yr. If a variety does not qualify for a patent, the Plant Variety Protection Act will provide some level of safety from unfair competition in the market. Support for enforcement efforts is important for everyone who shares in the value of enhanced seed traits.

### Barriers to Industry's Opportunities

Certainly, there will be many opportunities to differ in opinion as the industry matures in its management and adoption of biotechnology. It is important that we

continue to manage these tools in a responsible manner. When identity preservation is mandated, we should make sure that segregation can and does happen. When new products come to market with stewardship responsibilities such as refuge management, we should support and implement those requirements with precision and when we have neighbors who choose to farm in a way contrary to our own, we should work closely with them in an effort to make room for their view and chosen practice of farming. Going forward we will face challenges from regulation and legislation. If we do not engage in this process our voice will not be heard and our freedom to operate will be negatively impacted. In the words of Plato, "Those that believe they are too smart to engage in politics are punished by being governed by those who are dumber." Lawmakers listen to constituents and it will be the increasing responsibility of everyone to engage this process and direct the course of our own governance.



# Biotechnology: Expanding the Biofuel Industry

MICHAEL A. COTTA, BRUCE S. DIEN, RODNEY J. BOTHAST, AND NANCY N. NICHOLS

The United States produced 1.6 billion gal of fuel ethanol last year, with approximately 95% of it produced using corn. Ethanol production has expanded dramatically since 1980 (Figure 1) and today accounts for use of 5% of corn production. Ethanol production is expected to continue to increase as states phase out the use of methyl tertiary butyl ether (MTBE) as a fuel oxygenate. The California Energy Commission has estimated that production capacity is expected to grow to more than 4 billion gal/yr by 2006 (MacDonald et al., 2001). In this brief review, the economic and technical aspects of ethanol production are explored as well as future prospects for increasing ethanol yield from corn.

## GOVERNMENT INCENTIVES FOR ETHANOL PRODUCTION

The growth in the use of fuel ethanol can be traced to environmental legislation and federal and state economic incentives. In 1990, the Clean Air Act amendment was passed, which required the use of oxygenated fuel and reformulated gasoline to reduce carbon monoxide emissions. Fuel oxygenates are ethanol, MTBE, and ethyl tertiary butyl ether (ETBE). Several midwestern states mandate the use of ethanol. The Federal Government also has encouraged the use of ethanol by exempting it from the federal gasoline excise tax. This tax exception was set to expire in 2000, but has since been renewed until 2006. Several midwestern states also introduced further financial incentives for ethanol. These incentives are designed to favor smaller ethanol plants, such as those built by farmer cooperatives. Typical is Minnesota's Tax incentive, which returns 20 cents/gal/yr for 10 yr for a maximum of 50 million gal/yr. Many ethanol plants designed around this incentive have since expanded capacity.

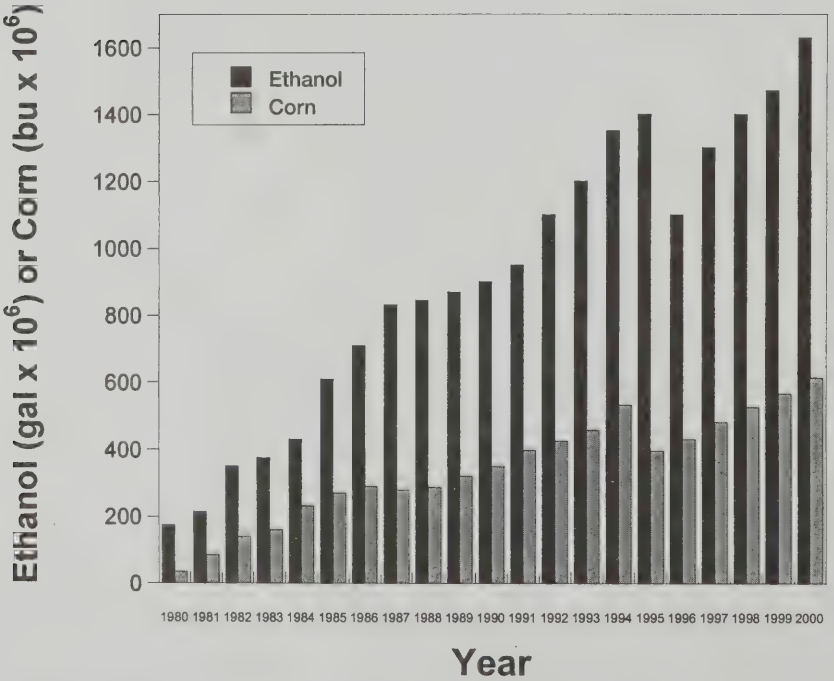



**Figure 1. Growth of ethanol production in the U.S. since 1980.**

Ethanol demand is expected to increase dramatically over the next several years as states begin to phase out the use of MTBE. MTBE, which has leaked from gasoline storage tanks, has been discovered to be a major groundwater contaminant and resilient to microbial degradation. As a result of these findings, California is phasing out the use of MTBE by 2003. In June, the Bush Administration refused California's request for a waiver of the

oxygenate fuel requirement. The annual California ethanol market is expected to grow by 500-800 million gal (McDonald et al., 2001). Eastern states are also moving to phase out MTBE. The markets for just Connecticut and New York are expected to increase by 290 million gal/yr by 2004. It is unlikely that all of this demand will be realized because of a compromise package being negotiated in Congress between the Governors' Ethanol Coalition and California.

Beyond its environment appeal, proponents of the use of fuel ethanol cite the following additional benefits: reduced reliance on Middle Eastern oil, lowered greenhouse gas emissions, and increased rural development. A careful study by the USDA has estimated that ethanol has a 25% net energy balance (Shapouri et al., 1995). Ethanol is available as a 10% v/v (E10) and 85% v/v (E85; only in the Midwest) blend with gasoline. E10 and E85 lower petroleum use by 6 and 74%, respectively (Wang et al., 1999). E10 also reduces green house gas emissions by 1% and E85 by 34% (Wang et al., 1999). Finally, ethanol is good for rural development by supplying an important market for corn and providing jobs at rurally located ethanol plants. In 1997, it was estimated that fuel ethanol increased farm income by $4.5 billion and led to the creation of 195,200 jobs (Evans et al., 1997).

## CURRENT ETHANOL PRODUCTION PROCESSES

Corn is processed to ethanol by either dry or wet milling. Last year, for the first time, dry milling production (55%) exceeded that of wet milling. The growth of dry mill capacity has exceeded that of wet mills because dry mills have lower capital costs. Capital costs for dry mills have been estimated as $1.25-1.50/gal. In recent times, no new wet mills have been built; instead, owners have relied on expanding existing facilities. Descriptions of the dry and wet milling processes follow.

## CORN DRY MILLING

The corn to ethanol dry milling process should not be confused with the dry mill process used for producing corn grits and flour and for that reason is sometimes referred to as a dry grind process. A schematic of a dry mill is shown as Figure 2 (for detailed reviews, see Jacques et al., 1999; Wyman, 1996). Corn is hammer milled to pass through a 1/8-3/16-inch screen. If the grits exit the mill too coarse, not all of the starch is available for fermentation.

Once ground, the corn is mixed with water to form a mash. The pH of the mash is adjusted to 6.0 with ammonia followed by the addition of 1/3 of alpha-amylase. Alpha amylase is added to begin to break down the starch polymer and produce soluble dextrins. The mash is heated to 121°C by using a jet cooker. The jet cooker is a special tube reactor/pump that uses direct steam heating to heat and shear the starch granules. The corn mash is kept at 121°C for 10 min by pumping it through a holding tube equipped with a backpressure valve. The mash flows from the holding tube into a flash tank and the temperature is allowed to fall to 80-90°C. The rest of the alpha-amylase is added and the mash is liquefied for 30 min. Liquefaction serves to greatly reduce the size of the starch polymer.

The liquefied mash is placed in the bioreactor and cooled to 32°C. The pH is lowered to 4.5-5.0 by using backset (recycled from the distillation column) and acid. The fermentation stage is started by adding the glucoamylase and the yeast inoculum. Glucoamylase converts liquefied starch into glucose by breaking down alpha-1,4 glucosidic linkages. Enough glucoamylase is added such that the saccharification of the starch to glucose, which occurs continually through the fermentation, does not limit the rate of ethanol production. In addition, either $(NH_4)_2SO_4$ or urea is added as a nitrogen source for the growth of the yeast. Recently, dry mills also have begun to add proteases that break down the corn protein to free amino acids, which serve as an additional source of nitrogen for the yeast. The fermentation lasts 48-72 h and has a final ethanol concentration of 10-12% vol./vol. The pH of the beer declines during the fermentation to below 4 by the action of carbon dioxide formed during the ethanol fermentation. The decrease in pH is important for increasing the activity of glucoamylase and inhibiting the growth of contaminating bacteria.

Dry milling plants can reduce the amount of glucoamylase added by saccharifying the liquefied starch before fermentation at 65°C. However, plants have gone to simultaneous saccharification and fermentation (SSF) because it lowers the opportunity for microbial contamination. SSF also lowers the initial osmotic stress of the yeast by avoiding a concentrated glucose solution.

Upon completion, the beer is first distilled through the beer column. The distillate is further concentrated to 95% (v/v) of ethanol, at which concentration water and ethanol form an azeotrope. The ethanol is brought up to 100% (v/v) concentration by using a molecular sieve bed. Finally, the ethanol is denatured with the addition of fusel oil, higher alcohols producing by the yeast during fermentation, and gasoline. Denaturation is required to avoid the alcohol beverage tax.

The stillage leaving the beer column is centrifuged with a decanter. Between 15 and 30% of the liquid fraction (thin stillage) is recycled as backset. The reminder is concentrated further by evaporation and mixed with the residual solids from the fermentation. The mixture is then dried to 9% moisture in gas-fired rotary dryer. The final product is marketed as distiller dried grains with solubles (DDGS). DDGS, ethanol, and (for some plants) $CO_2$ are the only products produced (Table 1).

Corn accounts for 60–70% of the cost of producing ethanol. There is some interest by seed companies to market specific hybrids for dry milling. We have recently compared three hybrids and determined that the fermentation efficiency, a measure of ethanol yield per available starch, varied among the hybrids. The significance of this finding is that both starch content and starch availability varies with hybrid. We also have compared the fermentation of *Bacillus thuringiensis* (Bt) versus non-Bt corn and found no differences in their fermentation properties.

## CORN WET MILLING

Wet mill plants are larger and produce more products than dry mills (Table 1; for detailed reviews, see Jacques et al., 1999; Wyman, 1996). Wet mills separate each component of the corn kernel: endosperm, germ, and pericap (e.g., corn hull). The endosperm is further separated into a starch and gluten (protein) streams. The

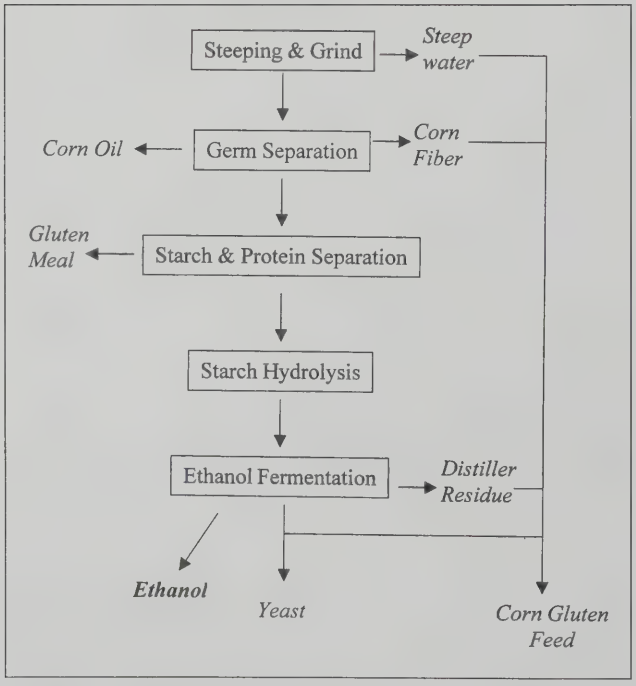



**Figure 2. Corn wet milling process for producing ethanol.**

**Table 1. Corn milling product yields and selling prices.**

| Co-Product | Yield (per bushel) | Selling Price (U.S. $) |
|---|---|---|
| *Corn Dry Grind Ethanol Fermentation* | | |
| Carbon dioxide | 16.7 lb | N.A. |
| DDGS[a] | 16 lb | 102/ton[b] |
| Ethanol | 2.65 gal | 1.40–1.60/gal[c] |
| *Corn Wet Milling Ethanol Fermentation* | | |
| Carbon dioxide | 15.8 lb | na |
| Corn oil | 1.83 lb | 0.158/lb[c] |
| Corn gluten meal | 2.60 lb | 275/ton[b] |
| Corn gluten feed | 11.2 lb | 67/ton[b] |
| Ethanol | 2.50 gal | 1.40-1.60/gal[c] |

N.A., not available.
[a] Distillers dried grains with solubles.
[b] Feedstuff, September 17, 2001 (Chicago prices).
[c] Chemical Market Reporter June 25, 2001 (Midwest Prices).

gluten is marketed as gluten meal, a high-protein (60%) animal feed used mainly by the poultry industry. Corn oil is extracted from the germ. The pericap is separated as corn fiber. The corn fiber is combined with the steep liquor and de-oiled germ cake and sold as corn gluten feed, a low-protein (20%) animal feed. In addition to producing ethanol, most corn wet millers produce other products from the starch by using either enzymatic or fermentation processes. Examples of these products are dextrin, high fructose corn syrup (HFCS), citric acid, amino acids, and lactic acid.

The key to isolating these different corn fractions is steeping (Figure 3). In the steeping process, the corn is soaked in water and treated with $SO_2$ (1600 ppm) at 52°C for 20–40 h. The corn is further acidified by the growth of lactic acid bacteria at later stages during the steep. Steeping swells the kernel and loosens the bonds between the protein and starch in the endosperm. After steeping, the kernels are shredded in a mill designed to dislodge the germ. The germ, which contains approximately 30% oil, is then separated based upon its lower density compared with the rest of the kernel with hydrocyclones. The recovered germ is next processed to extract the corn oil and the residual germ meal is blended into corn gluten feed.

The protein and starch are then separated from the fiber by passing the slurry along metal screens. Although the fiber is retained on the screens, the protein and starch pass on through. The fiber is further washed to recover additional starch and finally folded into the corn gluten feed. The protein is next separated from the starch, based upon density using disc-nozzle centrifuges. The recovered

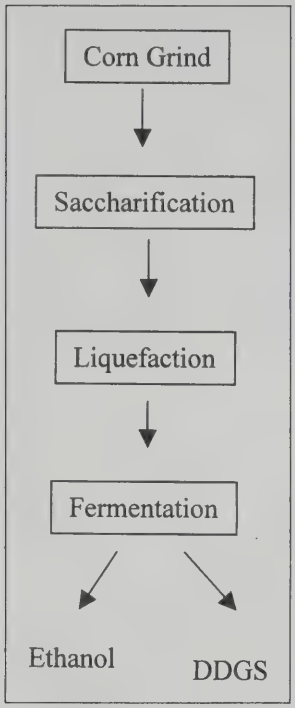



**Figure 3. Corn dry milling process for producing ethanol.**

protein (gluten) is sold as gluten meal. The recovered starch is further washed to remove residual protein. The cleaned starch, if used for ethanol or HFCS production, is enzymatically hydrolyzed to glucose by using alpha amylase followed by glucoamylase. As with dry milling, a jet cooker is used during the liquefaction step. Separate saccharification and fermentations steps are carried out. To aid in saccharification, pullanase is added with the glucoamylase. The fermentation is often run continuously in a cascade scheme, which reduces the amount of dried yeast needed. Ammonia or urea as well as liquid recovered from the steeping also are added to the fermentation broth. Foaming is often a problem in wet mill fermentations, because the corn oil has been removed, which necessitates the addition of antifoam.

Recently, some corn seed companies have begun marketing hybrids as being superior for wet milling. Traditionally, corn hybrids were evaluated on yield and starch content. Eckoff et al. (1993) developed a method for simulating the wet mill process in a laboratory. The results have shown that hybrids with similar starch content can still vary in extractable starch content. The superior hybrids are rated for high extractable starch content.

## LIGNOCELLULOSIC BIOMASS CONVERSION

Approximately 11% of the carbohydrates present in corn are not in the form of starch. These fractions consist of cellulose and xylan present in the hull (i.e., pericap) and germ meal fractions and are sold as part of corn gluten feed (wet milling) and DDGS (dry milling). Potentially, much of this fiber could be converted to ethanol without reducing the value of the feed because animal feed is sold on a protein basis. Consequently, these feedstocks are good candidates to be used for ethanol production because they are already present at ethanol plants. The amount of ethanol that could be produced is significant (Table 2). Fermentation of fiber in a dry mill operation probably requires the process to be modified. If the fiber fraction is collected following fermentation, it will be mixed in with the yeast and other insolubles. There are several possible modifications that might allow for fermentation of the fibrous fraction. One scheme would be to implement the quick soak process, developed by Agricultural Research Service and University of Illinois researchers, which allows for the germ to be collected before fermentation (Singh et al., 2001). In addition to the fibrous component of the kernel, the rest of the corn plant (e.g., corn stover) also could serve as a feedstock for ethanol. Corn stover contains 58% carbohydrates (Table 2) and it has been estimated that 30% of the corn stover could be harvested without affecting soil properties. Unlike DDG and corn fiber, collecting and storing corn stover represents a formidable challenge. However, fermenting available corn stover could conceivably boost ethanol production 10-fold. There is a commercial corn stover collection facility in Harlan, IA (Glassner et al., 1998).

A considerable amount of research has gone into developing processes for conversion of lignocellulosic biomass into ethanol. A simplified schematic of such a process is shown as Figure 4. Although size reduction is not be

**Table 2. Potential ethanol production from corn fibrous fractions.**

| Biomass | Carbohydrate *(% wt/wt)* | Starch *(% wt/wt)* | Cellulose *(%wt/wt)* | Xylan *(%wt/wt)* | Availability *(ton/yr)* | Ethanol[a] *(gal/yr)* |
|---|---|---|---|---|---|---|
| Corn Stover | 58.4 | — | 36.4 | 22 | $125–200 \times 10^9$ | $7.5–12 \times 10^9$ |
| Corn Fiber[b] | 69.6 | 19.7 | 14.1 | 32.4 | $3.4 \times 10^6$ | $385 \times 10^6$ |
| DDGS | N.A. | N.A. | N.A. | N.A. | $3.0 \times 10^6$ | $133 \times 10^6$ |

N.A., not available.
[a] Assumes theoretical ethanol yield.
[b] Availability includes all wet milled corn.

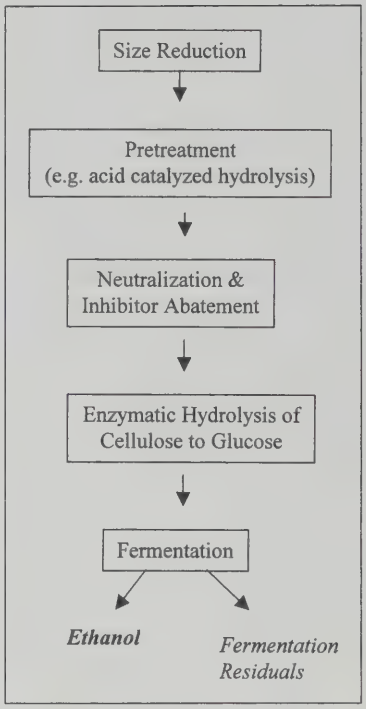



**Figure 4. Lignocellulose conversion to ethanol.**

required for treatment of corn fiber, some type of milling is needed for corn stover. A successful pretreatment step should accomplish multiple goals: 1) converting the xylan fractions to monosaccharides in high yields, 2) forming a minimum of inhibitors, and 3) making the cellulose fraction susceptible to enzymatic hydrolysis by cellulases. Inhibitors are formed by degradation of free sugars, after complete hydrolysis, freeing of organic acid side groups from the xylan (e.g., acetate), and lignin breakdown products. Conditions that optimize cellulose recovery also tend to favor degradation of the xylan sugars and, therefore, optimal pretreatment conditions require a compromise. A variety of pretreatments have been investigated for biomass and the best pretreatment, as expected, depends upon the source of biomass.

Most pretreatments are either chemical or a combination of chemical and physical. The most popular pretreatments are dilute acid, strong acid, alkaline hydrogen peroxide, ammonium fiber explosion, steam explosion with $SO_2$, and hot water. Pretreating with acid is capable of completely hydrolyzing the xylan fraction. Alkali and hot water methods only dissolve and partially hydrolyze xylan; thus, hydrolysis needs to be completed using either enzymes or acid. Steam explosion tends to be more destructive to pentose sugars than some of the other methods. Acid pretreatments are the only ones that have been used commercially, albeit decades ago. For efficient recovery of the xylan sugars, the cellulose fraction needs to be hydrolyzed in a separate step.

Hydrolysis of the cellulose fraction can be accomplished enzymatically or chemically. Acid hydrolysis, under sufficiently harsh conditions, can completely hydrolyze cellulose to glucose. However, these harsh conditions lead to the formation of inhibitors, thus (in the literature) enzymatic digestion has been favored. Often, the cellulase enzymes are added to the fermentation broth and carried out as a simultaneous saccharification and fermentation. Carrying out hydrolysis during the fermentation lowers the amount of enzyme required and circumvents the sensitivity of the cellulase enzymes to end production inhibition. Even when the best treatment for pretreating cellulose is used, cellulase loading is much higher than that needed for amylases. Thus, the cost of cellulases is considered a major technical hurdle to implementing biomass fermentations.

Fermentation of the sugars recovered from the xylan fraction is problematic because the traditional yeast, *Saccharomyces cerevisiae*, does not ferment pentoses. Naturally occurring yeast that do ferment xylose require aeration for growth; have low productivity; are acutely sensitive to inhibitors, especially acetate; and have fairly low ethanol tolerances. There are no suitable naturally occurring bacteria for fermenting xylose to ethanol (Bothast et al., 1999). Therefore, research has focused upon developing recombinant organisms to ferment pentoses to ethanol. Two strategies have been used to develop the needed biocatalyst: 1) expressing genes needed for xylose utilization in efficient ethanol producers or 2) expressing genes needed for ethanol production in bacteria capable of using xylose. As examples of the first approach, one *Saccharomyces* sp. and multiple *Zymomonas mobilis* strains have been constructed that metabolize xylose. Examples of the second approach are ethanologenic *Escherichia coli* and *Klebsiella oxytoca*. We have compared several of these recombinant organisms for fermentation of corn fiber hydrolysate (Table 3; Bothast et al., 1999).

We have developed ethanol-producing *E. coli* that convert sugar mixtures to ethanol with yields that are 93–95% of theoretical. The strains have been constructed to be genetically stable, to selectively produce ethanol, and to be tolerant of inhibitors found in hydrolysates (Dien et al., 2001). We also have begun to develop strains especially suited for fermentation of sugar mixtures. Most bacteria, including *E. coli*, only ferment pentoses after glucose has been exhausted from the medium and often xylose utilization is incomplete. These new strains carry an additional mutation that allows for simultaneous use of glucose and pentose sugars (Nichols et al., 2001).

We have demonstrated on a research scale the feasibility of converting corn fiber to ethanol (Dien et al., 1999). Specifically, the xylan portion was fermented, which left the cellulose fiber available for use in animal feed. The corn fiber was mixed with dilute acid (1.1 % [v/v] sulfuric

**Table 3. Comparison of recombinant microorganisms for production of ethanol.**

| Pretreatment | Strain | Max. Ethanol (g/l) | Yield (g/g)[a] | Max. Productivity (g/l/h) |
|---|---|---|---|---|
| Dilute acid | *E. coli* K011 | 34.7 | 0.41 | 1.16 |
| Dilute acid | *E. coli* SL40 | 31.7 | 0.42 | 1.12 |
| Dilute acid | *E. coli* FBR3 | 28.0 | 0.46 | 0.97 |
| Dilute acid | *Zymomonas* CP4 (pZB5) | 22.6 | 0.47 | 1.05 |
| AFEX | *Saccharomyces* 1400 (pLNH32) | 21.0 | 0.50 | 1.60 |

[a] Grams ethanol per grams sugar consumed; maximum possible is 0.51 g/g.

acid) to form a 17% (dry wt/total wt) solids loading. The mixture was pumped into a reactor vessel equipped with an external jet siphon mixer and a steam jacket. The slurry entered the reactor through the jet siphon, thereby heating it with direct steam (220°C). The corn fiber was held in the tank for 15 min at 145°C. The liquid portion was recovered for fermentation. The hydrolysate syrup contained a total of 76 g/l of sugars, which is 95% of theoretical, excluding cellulose, which remained with the solids.

The corn fiber hydrolysate was next overlimed to remove inhibitors. This process consists of adjusting the pH to 10 with $Ca(OH)_2$ and treating the hydrolysate to 90°C for 30 min. The hydrolysate was neutralized with sulfuric acid to pH 7 and the resulting gypsum formed removed by centrifugation. Yeast extract and tryptone were added as nitrogen sources. The hydrolysates were fermented using an ethanologenic *E. coli* strain. The fermentation was completed within approximately 65 h and the ethanol yield was 92% of theoretical. Residual xylose was 3.5 g/l.

## SUMMARY

Last year, 1.6 billions gal of fuel ethanol was produced in the Unites States, almost all of which was produced from corn. Ethanol demand is expected to more than double in the next several years as states ban the use of MTBE as a fuel oxygenate, provided Congress decides to retain the fuel oxygenate requirement. Corn can be prepared for ethanol fermentation by wet or dry milling the kernels. Today, dry milling is the more popular process because of the increasing number of farmer cooperatives being formed for ethanol production. We have been researching method for increasing ethanol production, as well as increasing its efficiency, by fermenting the fibrous components of the kernel. Fermenting these nonstarch fractions could increase the ethanol yield from a bushel of corn by a maximum of 10%.

## REFERENCES


Bothast, R.J., N.N. Nichols, and B.S. Dien. 1999. Fermentations with new recombinant organisms. *Biotechnology Progress* 15: 867-875.

Dien, B.S., L.B. Iten, and R.J. Bothast. 1999. Conversion of corn fiber to ethanol by recombinant *Escherichia* coli strain FBR3. *Journal of Industrial Microbiology and Biotechnology* 22: 575-581.

Dien, B.S., N.N. Nichols, P.J. O'Bryan, and R.J. Bothast. 2001. Development of new ethanologenic *Escherichia coli* strains for fermentation of lignocellulosic biomass. *Applied Biochemistry and Biotechnology* 84-86: 181-196.

Evans, M.K. February 1997. The economic impact of the demand of ethanol. Midwestern Governors' Conference.

Glassner, D.A., J.R. Hettenhaus, and T.M. Schechinger. 1998. Corn Stover Collection Project. Department of Energy Report.

Jacques, K., T.P. Lyons, and D.R. Kelsall. 1999. *The Alcohol Textbook: A Reference for the Beverage, Fuel and Industrial Alcohol Industries*, 3rd ed. Nottingham University Press. Nottingham, UK.

MacDonald, T., G. Yowell, and M. McCormack. August 2001. U.S. Ethanol Industry; Production Capacity Outlook. California Energy Commission. P600-01-017.

Nichols, N.N., B.S. Dien, and R.J. Bothast. 2001. Use of catabolite repression mutants for fermentation of sugar mixtures to ethanol. *Applied Microbiology and Biotechnology* 56: 120-125.

Shapouri, H., J.A. Duffield, and M.S. Graboski. July 1995. Estimating the Net Energy Balance of Corn Ethanol. USDA Economic Research Service, Office of Energy. Agricultural Economic Report. No. 721.

Singh V., K.D. Raush, P. Yang, H. Shapouri, R.L. Belyea, and Tumbleson, M.E. July 2001. Modified dry grind ethanol process. Agricultural Engineering Department, University of Illinois. UILU No. 2001-7021.

Wang, C., C. Saricks, and D. Santi. January 1999. Effects of fuel ethanol use on fuel-cycle energy and greenhouse gas emissions. Argonne National Laboratory. Repot ANL/ESD-38.

Wyman, C.E. 1996. *Handbook on Bioethanol: Production and Utilization*. Taylor and Francis, Washington, DC.

# Biotechnology: The Good, The Bad, and The Ugly

DAVID A. LIGHTFOOT

## INTRODUCTION

With recent advances in molecular biology, the products of biotechnology are becoming commonplace in the agricultural and medical community. Biotechnology-derived bacteria have been used in the manufacture of drugs, cheese making, and in dietary supplement synthesis since the 1980s (Glick and Pasternak, 1998). Biotechnology-derived crops that are extremely important to Illinois agriculture and the Illinois economy are Roundup Ready soybean, Liberty Link corn, and *Bacillus thuringiensis* (Bt) corn. They combine to have represented 45–75% of the total crop from 1996 to the present

Roundup Ready soybean are a genetically engineered variety of soybean that contains partial gene sequences from a cauliflower mosaic virus, a petunia, and a bacterium (Padgette et al., 1995). One of the bacterial genes codes for resistance to glyphosate, the herbicide Roundup, which is manufactured by Monsanto. The other gene sequences are intended to control the expression of the glyphosate gene. As a result, Roundup can be used to kill weeds in soybean crops without injuring the soybean itself (Delanney et al., 1995; Athey and Harrison, 1999).

Liberty Link corn hybrids are a genetically engineered variety of corn that contains partial gene sequences from a cauliflower mosaic virus and a fungus-like bacterium (Glick and Pasternak, 1998). One of the bacterial genes codes for resistance to gluphosinate, the herbicide Liberty, which is manufactured by Agrevo. The other gene sequences are intended to control the expression of the gluphosinate resistance gene. As a result, Liberty can be used to kill weeds in soybean crops without injuring the soybean itself.

Bt corn is transgenic corn containing different *B. thuringiensis* genes that encode protein toxins that selectively kill some species of Lepidoptera, including larvae of the European corn borer and corn earworm. The insects die when the Bt toxins in corn tissues bind to digestive tract receptors. They are more complex in that one of several protein toxin genes can be used, depending on the target pest.

## THE GOOD

With the United States producing most of the world's corn and soybean and exporting about half of its crop and derived products (meat, oil) to Europe and Asia, the economic benefits of Roundup Ready soybean, Liberty Link corn, and Bt corn are significant. Weeds reduce farmers yields by approximately $4 billion and farmers spend approximately $1 billion per year controlling these losses (Glick and Pasternak, 1998). Many of these "traditional" chemicals, including halogenated cyclic hydrocarbons, are mobile in groundwater and persistent, and can be found in water supplies throughout the Midwest. When they degrade, the benzene ring structures persist and accumulate in the environment. In contrast, Roundup and Liberty, linear phosphorylated hydrocarbons, tend to bind tightly to the soil and degrade completely. Furthermore, Liberty is a natural product of some soil microbes (the source of the resistance genes) found at low levels in many soils. Likewise, annual U.S. damage from European corn borer alone reaches nearly $1 billion and farmers spend nearly $300 million on chemicals and application costs (e.g., fuel, personnel) to control this pest. In addition, the engineered products kill only some insects, not all those in the field, thereby reducing the "Silent Spring" impact. Therefore, the use of Bt is a major advance for the farmer and a sustainable agriculture. By reducing reliance on expensive conventional pesticides, Bt varieties are sweeping the U.S. Corn Belt, accounting for 30% of 1999 corn acreage.

## THE BAD

The term genetically modified organism (GMO) has become synonymous with biotechnology products, although it was coined to emphasize the equivalency of breeder's cultivars and biotechnology-enhanced cultivars. These GMO crops are at the center of the controversy concerning the safety and desirability of biotechnology-supplemented food and gene release into the environment. There are global concerns over the use of genetically modified organisms in the international market (Table 1; Ho, 1998; Hoban, 1998). In fact, the European Union has systematically tightened GMO regulation since their introduction (Hubner et al., 1999). The concerns surrounding GMO crops focus on unexpected effects of environmental release and food safety. The popular press has printed articles claiming these effects include monarch butterfly mortality in Bt cornfields, human allergic reaction to Bt food (Starlink), increased pathogen disease in GMO crops, and rat mortality in GMO feeding studies. Concerns surrounding the products of biotechnology have prompted a reexamination of the safety issues for the crops. Scientific reanalysis of two of these three phenomena are recently available.

## MONARCH BUTTERFLY MORTALITY: LESS THAN FEARED

In 1999 it was reported that Bt corn transgenic event Bt186 from Novartis contains a variant of a gene for a Bt toxic protein that makes corn pollen poisonous to monarch butterflies (Losey et al., 1999). If this gene-crop combination had been planted in a large acreage, it could have depressed the monarch butterfly population by 5-7% per year. Fortunately, pollen expression is unusual for Bt events and Bt186 is only planted in 2% of the acreage. Furthermore, pollen doses of 500-600 grains per milkweed leaf are necessary for kill, which is very high for plants more than a few meters from a cornfield. Recently, several studies by four independent investigator teams from academia were published in *Proceedings of the National Academy of Sciences of the United States of America* (Hellmich et al., 2001; Oberhauser et al., 2001; Pleasants et al., 2001; Sears et al., 2001; Siegfried et al., 2001; Stanley-Horn et al., 2001; Zangerl et al., 2001) suggest that the effects of naturally occurring Bt corn pollen-derived butterfly mortality is less than 1 larvae in 2,000 exposed (0.05%). Such low mortality rates will have no noticeable effect on butterfly populations and will certainly be less than that by the use of traditional nonselective insecticides.

**Table 1. Sudden death syndrome group and herbicide treatment means within maturity group.**

| Cultivar/Herbicide | MG II | MG III | MG IV | MG V | MG VI |
|---|---|---|---|---|---|
| **Infection Severity (IS)** | | | | | |
| SDS-susceptible | 64 A | 62 A | 45 A | 45 A | 52 A |
| SDS-tolerant | 50 A | 54 A | 26 B | 37 A | 42 B |
| Herbicide spray | 54 A | 59 A | 37 A | 40 A | 47 A |
| No herbicide spray | 59 A | 57 A | 34 A | 41 A | 46 A |
| **Colony Forming Units (CFU)** | | | | | |
| SDS-susceptible | 620 A | 358 A | 554 A | 791 A | 859 A |
| SDS-Tolerant | 397 A | 225 A | 371 A | 378 A | 291 B |
| Herbicide spray | 560 A | 272 A | 443 A | 528 A | 491 A |
| No herbicide spray | 457 A | 311 A | 482 A | 625 A | 659 A |
| **Disease Index (DX)** | | | | | |
| SDS-susceptible | 3.7 A | 8.5 A | – | 4.9 A | 10.3 A |
| SDS-tolerant | 2.1 B | 0.8 A | – | 0.1 A | 1.9 B |
| Herbicide spray | 2.8 A | 4.5 A | – | 1.8 A | 6.1 A |
| No herbicide spray | 3.0 A | 4.8 A | – | 3.1 A | 6.2 A |

## INCREASED DISEASE IN GMO CROPS: SUDDEN DEATH SYNDROME (SDS) COINCIDENCE

The development of Roundup Ready soybean allowed the use of the herbicide Roundup Ultra for weed control in food crops. However, 1997, the first year of extensive Roundup Ready soybean planting in the United States, coincided with a severe epidemic of a fungal disease of soybean known as sudden death syndrome (SDS; O. Myers Jr., personal communication). SDS is a disease of soybean that kills plants and reduces yield for growers by 4% over a whole state and by 50% in some fields (Wrather et al., 1997). It has been getting worse in the Midwest since 1980. In 1998 and 1999, Njiti et al. (2002a,b) looked at the effect on SDS of Roundup Ultra application to Roundup Ready soybean. Roundup Ready varieties of soybean that can grow across Illinois were selected that were either SDS-resistant or SDS-susceptible. Disease was measured at four locations in central Illinois or four locations in southern Illinois between 1998 and 1999. Data from all experiments were analyzed with statistical tests. The duplicate plants were either sprayed or not sprayed when the plants germinated. When the plant flowered root colonization by the fungus *Fusarium solani* was measured as the percentage of infected root discs and the number of colonies in a gram of root tissue (Njiti et al., 2002a). Plants in plots that were treated with Roundup Ultra did not show more infection than those in plots that were not treated with Roundup Ultra. The

degree of root infection by the fungus was the same for both treated and untreated plots. There were significant differences in SDS resistance between plants, with the SDS-tolerant cultivars showing less root infection than the SDS-resistant cultivars. The leaf scorch of SDS caused by the fungus was measured a percentage. Leaf scorch broadly paralleled the infection data but was not very severe in 1999 (<10%), reducing the statistical validity of that measure. However, there are SDS-tolerant Roundup Ready cultivars that can be selected by farmers with SDS in their fields. Spraying Roundup Ultra will not make SDS worse. The association with Roundup Ready soybean release was a coincidence.

## THE UGLY

### Extinctions

The principle remains–insects that depend on rare weed species for reproduction could be driven to early extinction by herbicide-tolerant GMOs that allow growers to keep field weed populations under control. Although extinction is an inevitable consequence of evolution by natural selection (Ridley, 1996), artificially driven loss of biodiversity caused by *Homo sapiens* does not allow for "normal" evolutionary progression where new species often arise by chance from populations on the brink of extinction.

### Overpopulation

Unfortunately, there are too many people. This overpopulation is felt less in the United States than other parts of the world. The United States contains some of the world's last wildernesses, but as elsewhere, these areas may have to be ploughed to support the projected 12 billion world population by 2050. GMOs do allow more crop production from the existing agricultural land. Genetic improvement of crops has underlain yield that consistently increased by 2–4% per year in the major crops since 1930 (Duvik, 1990; Specht et al., 2000). Concomitant with yield, fertilization needs have increased, promoting nitrogen runoff. Another consequence of yield improvement has been a restricted genetic base and increasing yield instability on a year-by-year basis (Duvick, 1991). Instability has resulted in localized failures to harvest the fertilizer inputs as yield and there is a need to avoid losses in these situations. Genetic improvement of elite germplasm will increasingly rely on transgenes and GMOs as natural genetic diversity decreases and becomes harder to use (Lightfoot, 2000; Miller, 1999).

### Allergies: Food Safety

Food safety issues have circulated on the toxic or allergenic ramifications of proteins produced by GMO plants such as Starlink (Fox, 2001). Some concerns are manufactured by scientific misconduct, such as the United Kingdom rat feeding study that showed a high rat mortality rate, but only in the control group deliberately fed a poison (the latter part not being reported until a day later). In part, some of the concerns may be justified and supported by recent findings showing that a gene from a Brazil nut, engineered into soybean, caused allergic reactions in sensitive humans (Nordlee et al., 1996). This reaction was not surprising because Brazil nuts have a gene that encodes for a methionine-rich seed storage protein of a class that causes allergic reactions in many nuts and grains, most notably peanuts and wheat. The major problem with allergenicity is that it is unpredictable for new proteins (Hefle et al., 1996). Certain classes of proteins are known to be more likely to cause widespread allergenicity than others, although the reason(s) is not clear. Furthermore, there are only rudimentary hyperallergic animal test systems (e.g., in rats and dogs) with which to pretest new GMO or non-GMO products. Using animal test systems involves a whole new set of ethical dilemmas. Whether by humans or animals, allergic reactions to GMO proteins can be tested for and removed before market, as with the Brazil nut protein GMO. Finally, there is a major increase in reported allergencity in human populations of developed countries that is coinciding with biotechnology products. In fact, studies suggest the cause of the allergenicity increase is insufficient exposure to infection. Children who do not "eat a bushel of dirt" by the time they are 6 yr old may be more likely to become allergic because their immune systems turns on normal environmental molecules.

Unfortunately, both allergens and plant-derived toxins also might be GMO-induced, although this potential has not yet been observed. The latter are hard to test for because they are unpredictable and require substantial equivalence of GMO and non-GMO crops. Equivalence indicates that the crop is not changed but is only as accurate and inclusive as the test system used (Miller, 1999). Crop plants have the potential to produce thousand of chemicals of unknown effects through secondary metabolism, such as with many plant-derived drugs (Wink, 1996). New techniques are regularly invented that can retest the apparent equivalence of transgenic crops and these should be applied vigorously and openly to existing GMO products (Sommerville et al., 2001). However, allergic reactions are more likely to occur

during traditional plant breeding when massive blocks of new genes are imported to a crop from a wild relative to increase biodiversity.

Significant numbers of individuals consider it possible that eating GMO crops could result in GMO transfers to animals and humans (Hoban, 1998). This debate is similar to the horizontal transfer concern of the GMO to weeds or microbes but in this instance is a food safety issue. Plant-to-animal gene transfers are the rarest of horizontal gene transfers. They are likely to occur on a geological timescale if the historical record contained in the genomes of plants and animals is being accurately interpreted (TAGI, 2000; Stanhope et al., 2001).

Finally, civil liberty and freedom of choice are impinged by GMO release without labeling requirements. Simply stated, one cannot at present choose not to eat GMOs without restricting diet unreasonably. Segregation and labeling will solve the problem for the consumer and ready the production chain for the 200 new GMO products in the pipeline for release.

## REFERENCES


Delannay, X, T.T. Bauman, D.H. Beighley. 1995. Yield evaluation of glyphosate-tolerant soybean lines after treatment with glyphosate. *Crop Sci.* 35:1461-1467.

Duvick, D.N. 1991. *Progress in Conventional Plant Breeding*. Springer Verlag, Amsterdam.

Fox, J.L. 2001. EPA re-evaluates StarLink license. *Nature Biotechnology* 19: 11.

Glick, B.R. and J.J. Pasternak. 1998. *Molecular Biotechnology: Principles and Applications of Recombinant DNA*, 2nd ed. American Society for Microbiology, Washington, DC.

Hefle, S.L., J.A. Nordlee, and S.L. Taylor. 1996. Allergenic foods. *Critical Reviews in Food Science Nutrition* 36 (Suppl): S69-S89.

Hellmich, R.L., B.D. Siegfried, M.K. Sears, D.E. Stanley-Horn, M.J. Daniels, H.R. Mattila, T. Spencer, K.G. Bidne, and L.C. Lewis. 2001. Monarch larvae sensitivity to *Bacillus thuringiensis*- purified proteins and pollen. *Proceedings of the National Academy of Sciences of the United States of America* 98: 11925-11930.

Ho, M.W. 1998. Dangerous liason-deadly gamble, in *Agricultural Biotechnology and Environmental Quality* (R.W.F. Hardy and J.B. Segelken eds), National Agricultural Biotechnology Council Report 10, NABC, Ithaca, New York, pp 105-120.

Hoban, T.J. 1998. International acceptance of agricultural biotechnology, in *Agricultural Biotechnology and Environmental Quality* (R.W.F. Hardy and J.B. Segelken eds), National Agricultural Biotechnology Council Report 10, NABC, Ithaca, New York, pp 55-76.

Hubner P, E. Studer, and J. Luthy. 1999. Quantitation of genetically modified organisms in food. *Nature Biotechnology* 17: 1137-1139

Lightfoot, D. 2000. GMO safety and science, in *Safety of Alternate Production Systems, Including GMOs* (R. Beck ed), Urbana, IL, pp 1-5.

Losey JE, Rayor LS, Carter ME. 1999. Transgenic pollen harms monarch larvae. *Nature* 399(6733):214.

Miller, H.I. 1999. Substantial equivalence: its uses and abuses. *Nature Biotechnology* 17: 1042-1043.

Njiti, V.N., O. Myers Jr., R. Buehler, and D.A. Lightfoot. 2002a. Glyphosate on Roundup Ready soybean: effects on root infection by *Fusarium solani* f. sp. *glycines* and sudden death syndrome *Proceedings of the National Academy of Sciences of the United States of America* (submitted).

Njiti, V.N. O. Myers Jr., R. Buehler, and D.A. Lightfoot. 2002b. Glyphosate on Roundup Ready soybean: effects on leaf scorch of sudden death syndrome. *Journal of Production Agricriculture* (submitted).

Nordlee, J.A., S.L. Taylor, J.A. Townsend, L.A. Thomas, and R.K. Bush. 1996. Identification of a brazil-nut allergen in transgenic soybeans. *The New England Journal of Medicine* 334: 688-692.

Oberhauser, K.S., M.D. Prysby, H.R. Mattila, D.E. Stanley-Horn, M.K. Sears, G. Dively, E. Olson, J.M. Pleasants, W.K. Lam, and R.L. Hellmich. 2001. Temporal and spatial overlap between monarch larvae and corn pollen. *Proceedings of the National Academy of Sciences of the United States of America* 98: 11913-11918.

Padgette, S.R., K.H. Kolacz, X. Delannay, D.B. Re, B.J. LaVallee, C.N. Tinius, W.K. Rhodes, Y.I. Otero, G.F. Barry, D.A. Eichholtz, V.M. Peschke, D.L. Nida, N.B. Taylor, and G.M. Kishore. 1995. Development, identification, and characterization of a glyphosate-tolerant soybean line. *Crop Science* 35: 1451-1461.

Pleasants, J.M., R.L. Hellmich, G.P. Dively, M.K. Sears, D.E. Stanley-Horn, H.R. Mattila, J.E. Foster, P. Clark, and G.D. Jones. 2001. Corn pollen deposition on milkweeds in and near cornfields. *Proceedings of the National Academy of Sciences of the United States of America* 98: 11919-11924.

Ridley, M. 1996. *Evolution*. Blackwell Science, Cambridge, MA.

Sears, M.K., R.L. Hellmich, D.E. Stanley-Horn, K.S. Oberhauser, J.M. Pleasants, H.R. Mattila, B.D. Siegfried, and G.P. Dively GP. 2001. Impact of Bt corn pollen on monarch butterfly populations: a risk assessment. *Proceedings of the National Academy of Sciences of the United States of America* 98: 11937-11942.

Stanhope, M.J., A. Lupas, M.J. Italia, K.K. Koretke, C. Volker, and J.R. Brown. 2001. Phylogenetic analyses do not support

horizontal gene transfers from bacteria to vertebrates. *Nature* 411: 940-944.

Stanley-Horn, D.E., G.P. Dively, R.L. Hellmich, H.R. Mattila, M.K. Sears, R. Rose, L.C. Jesse, J.E. Losey, J.J. Obrycki, and L. Lewis. 2001. Assessing the impact of Cry1Ab-expressing corn pollen on monarch butterfly larvae in field studies. *Proceedings of the National Academy of Sciences of the United States of America* 98: 11931-11936.

Wink, M. 1996. Special nitrogen metabolism, in *Plant Biochemistry* (P.M. Dey and J.B. Harborne eds), Academic Press, London.

Wrather, J.A., T.R. Anderson, D.M. Arsyad, J. Gai, L.D. Ploper, A. Porta-Puglia, H.H. Ram, and J.T. Yorinori. 1997. Soybean disease loss estimates for the top 10 producing countries in 1994. *Plant Disease* 81: 107-110.

Zangerl, A.R., D. McKenna, C.L. Wraight, M. Carroll, P. Ficarello, R. Warner, and M.R. Berenbaum. 2001. Effects of exposure to event 176 Bacillus thuringiensis corn pollen on monarch and black swallowtail caterpillars under field conditions *Proceedings of the National Academy of Sciences of the United States of America* 98: 11908-11912.

# What Do We Know About Grape Colaspis?

**MICHAEL ROEGGE, MATTHEW MONTGOMERY, AND RANDALL WRIGHT**

Historically, grape colaspis has not received much attention from producers and researchers. Until recently, it was thought of as a "secondary" insect pest in Illinois. However, if producers in west central Illinois were surveyed, they would rank grape colaspis as their primary insect pest. Unlike its relative, the western corn rootworm, there is limited research data published on grape colaspis. Most publications date in the 1920s and 1930s and were written by John Bigger, with one article by Dale Lindsay from Iowa State College (now Iowa State University) in 1943. After a 60-yr hiatus, grape colaspis research is being conducted in Illinois to determine the economic impact of this pest on corn and soybean and to evaluate monitoring techniques that may assist producers in predicting economic injury in fields before planting begins.

Information on the life cycle and biology of grape colaspis in Illinois may provide insight into ways to monitor and predict future economic injury. Grape colaspis larvae feed on the root hairs of host plants, resulting in an inability to take up sufficient moisture and nutrients. The greatest damage is done to corn and soybean, but damage can occur in other legumes, such as alfalfa and clover. Aboveground symptoms in corn include purple leaves and stems, reduced height, wilting and stunting, and seedling death in severe infestation. In soybean, aboveground symptoms include stunting and reduced stands. Generally, the most severe injury occurs in corn, but several cases of soybean damage have been reported. Damage may not always be attributable to grape colaspis, because herbicide injury symptoms may mimic those of grape colaspis, or other pests, such as southern corn leaf beetle.

Beginning in spring 2001, a research project was initiated to identify an effective method of predicting economic injury and establishment of an economic threshold for grape colaspis. The various sampling methods evaluated in corn and soybean fields included spring and fall soil sampling for a larval population, wireworm bait stations, colored sticky traps, and sweep net samples of soybean fields. Spring and fall soil sampling was done in fields in west central Illinois. Preliminary results indicate soil sampling may yield better results if sample selection is based on soil type. Due to the clumped distribution of larvae within fields, random soil samples may not accurately reflect grape colaspis populations. Fall soil sampling was not conducted to the extent of spring sampling. Fall sampling may provide better results than spring sampling and larger soil samples taken within the row may better predict larval injury. Sweep net sampling showed some promise, whereas bait stations commonly used to evaluate wireworm populations do not appear to attract grape colaspis larvae. Three commercially available colored sticky traps (yellow, lime green, and white) were monitored in corn and soybean fields, and adults did not show significant differences in color preference based on the number of beetles attracted to the traps. From field observations, adults do not fly much, thus traps may not be as useful for grape colaspis as they are for western corn rootworm.

Soil types may play a part in determining abundance of grape colaspis. Eaton (1978) showed that females preferred to lay eggs in clay loams compared with other soils. The clay loams are apt to become creviced, which enables females to lay eggs deeper in the soil profile than in other soil types. Lindsay (1943) observed that the heaviest infestations occurred on silt loams. Larval and egg survivorship may be higher in more friable soil, thus explaining why there is more damage in west central Illinois compared with other areas in the state.

As more research is completed, the behavior of grape colaspis will become better defined and this information

may provide insight to monitoring and control. There are still many unanswered questions: Does early feeding damage translate into yield loss at harvest? Do any of the current products control grape colaspis? and Is there an effective method of sampling to monitor populations in the field? These questions may be answered as more attention is devoted to this secondary insect pest.

# New Directions in Scouting for Soybean Cyst Nematode

**TERRY NIBLACK AND GREG TYLKA**

Nematologists throughout the Midwest have been working to improve and standardize our methods of assessing populations of soybean cyst nematode (SCN). Standardization will benefit all soybean growers because it will improve our ability to interpret SCN research done in other states–but in equivalent maturity zones. As a result, changes are in the works for the way we, in Illinois, assess SCN populations in farmers' fields. We emphasize how recent research has affected recommended sampling techniques, and compare the utility of cyst assays to egg assays for initial diagnosis and monitoring the effects of production strategies for management of SCN. In addition, the familiar system of races of SCN will be phased out over the next few years. The details of the new system, the HG Type test, are explained, along with an assessment of the impact of the system on seed labeling, resistance testing, and management recommendations. This year, the soybean varieties in the Variety Information Program for Soybeans (VIPS) were assessed for SCN resistance to three different populations, and we explain how to interpret these results and use them in variety selection.

# So You Think You Have a Herbicide-Resistant Pigweed?

**AARON G. HAGER AND PATRICK J. TRANEL**

Proper herbicide application usually results in excellent control, but sometimes things go wrong. Poor weed control may result from improper application, untimely weather conditions, or from the dreaded R-word: **resistance**. In Illinois, there are now at least nine weed species in which resistance to one or more herbicide modes of action has been confirmed. If you have problems controlling a weed with a particular herbicide and suspect resistance, how do researchers determine whether herbicide resistance has indeed developed? What additional studies do they conduct to investigate the resistant biotype and, more importantly, what are the implications of their findings to retail applicators and producers? Typically, weed scientists use greenhouse efficacy studies to determine both the magnitude of herbicide resistance and cross-resistance to other herbicides. Biochemical assays of the herbicide target site and studies of herbicide uptake, translocation, and metabolism are used to determine the mechanism of resistance. These studies are typically followed with genetic and molecular investigations to determine the inheritance of the resistance trait and to determine the basis of resistance at the molecular (gene) level. Results of the genetic and molecular studies can reveal insights into how the resistance evolved and how it might spread. Ultimately, the goal of these investigations is to better predict the situations in which herbicide-resistant biotypes are likely to develop, and to learn how to manipulate weed management strategies in ways that reduce the likelihood for future resistance evolution.

# Herbicide Calculations and Formulations. What Does It All Mean?

**JEFFREY A. BUNTING, LAWRENCE E. STECKEL, AND CHRISTY L. SPRAGUE**

Herbicides are routinely used to obtain weed control in production agriculture. With more than 57 corn and 44 soybean herbicides listed in the most recent edition of the *Illinois Agronomy Handbook*, the days of having only a few corn or soybean herbicides to choose from are long gone. Remember, "Can 'em and confuse 'em"? The trend towards premix products continues, as does the commercialization of "generic" or private brand herbicide formulations. With this array of herbicides comes a vast assortment of formulations, rates, active ingredients, acid equivalents, additives already formulated with the product, and additives that need to be added. Are these all really created equal? Do formulations, active ingredient, and acid equivalents make a difference in weed control? What does it all mean?

Each herbicide "specializes" in how it works to control a weed, yet all herbicides share some similarities. All herbicides must find a way into the target plant, move to a specific location within the plant, and bind at a specific target site within the plant. Herbicide formulation, rate, active ingredients, acid equivalents, and spray additives can influence each of these processes. How does active ingredient differ from acid equivalent, and why can it make a difference in weed control? Is an ester or amine formulation of 2,4-D better to use for a burndown application? How about for a postemergence application in corn? Is there an easy way to calculate the amount of each premix component?

# Western Corn Rootworm: New Insights into an Old Problem

**CHRIS PIERCE, TIM MABRY, AND MATTHEW O'NEAL**

The failure of a corn-soybean rotation to manage corn rootworms in Illinois and Indiana has been attributed to a new strain of western corn rootworm whose females lay at least a portion of their eggs in soybean fields. A summary of recent research focuses on the behavioral changes that have allowed this new strain to become apparently "resistant" to crop rotation. An overview of field and laboratory work is presented from the University of Illinois and Michigan State University. Sampling for rootworm eggs in corn and soybean fields has revealed the degree and timing of western corn rootworm egg-laying in east central Illinois. Insights from this "on-farm" study suggest that the seasonal development (phenology) of corn influences western corn rootworm egg-laying in soybean. Results from a 2001 survey of soybean fields indicate the current abundance and distribution of western corn rootworm adults in Illinois. A discussion of factors influencing adult western corn rootworm movement includes results from research of adult migration from cornfields, seasonal distribution between corn and soybean, and how adult feeding on soybean effects behavior and egg-laying. Research at Michigan State University suggests that advancing corn phenology increased western corn rootworm acceptance of soybean as an alternate feeding site, and is focused on how this decreased affinity for corn may result in dispersal from corn, and movement into and subsequent egg-laying in soybean. A discussion of Michigan field research relays how delayed adult emergence and a decreased affinity for corn in a late phenological stage by this new strain of western corn rootworm could result in rotation failures.

# New Insights into an Old Problem: The View on Western Corn Rootworm from Michigan

**MATTHEW O'NEAL, DAVE MEEK, DOUG LANDIS, AND CHRIS DIFONZO**

Recently, western corn rootworm (*Diabriotica virgifera virgifera* LeConte) has started laying eggs in soybean (*Glycine max* L.) where a corn (*Zea mays* L.)-soybean rotation is routinely practiced, causing significant damage (Levine and Gray, 1996; O'Neal et al., 2001a). At Michigan State University, we are investigating factors related to the behavior(s) that influences western corn rootworm oviposition in soybean fields, and we are attempting to characterize both behavioral and physiological characteristics that have resulted in western corn rootworm adaptation to crop rotation.

## CURRENT HYPOTHESIS/MODEL

In a corn-soybean rotation, larvae from eggs that are oviposited into and overwinter in soybean, emerge in a cornfield the following spring. Alternatively, in areas of intensive corn-soybean rotation, larvae emerge the following year in a nonhost field (i.e., soybean). Because western corn rootworm do not have an expanded larval feeding range that includes soybean, or an extended diapause (Levine and Gray, 1996; Levine and Oloumi-Sadeghi, 1996), there appears to be a selective advantage for female western corn rootworm to lay eggs in soybean. Accordingly, O'Neal et al. (1999) found greater numbers of adult western corn rootworm in soybean versus cornfields in east central Illinois. They also found a greater percentage of adult females in soybean than in cornfields during August (O'Neal et al., 1999), when western corn rootworm females probably lay most of their eggs (Hein and Tollefson, 1985).

The current model for how western corn rootworm became resistant to rotation emphasizes the widespread adoption of a corn-soybean rotation (Sammons et al., 1997). Within a landscape that is predominately rotated corn and soybean, a selective advantage is realized by western corn rootworm that expand their egg-laying to include soybean fields. Throughout this article, we refer to western corn rootworm that lay eggs in soybean as variant western corn rootworm, referring to a behavioral variety different from those that were thought to only lay eggs in cornfields. However, this model does not clearly state what has changed in variant western corn rootworm egg-laying behavior to confer such a selective advantage within this landscape.

Knowing the mechanism by which this apparent resistance to rotation has occurred is crucial for development of improved management strategies. The initial prediction of an attraction to soybean (Sammons et al. 1997) was refuted, suggesting that movement out of cornfields is the initial behavior that results in the subsequent failure of crop rotation (Spencer et al., 1999). Below, we summarize some of our results that have led us to investigate the role advancing corn phenology plays to increase western corn rootworm acceptance of soybean as an alternate feeding and potential oviposition site. We propose an expanded model for western corn rootworm adaptation to a corn-soybean rotation and suggest that western corn rootworm response to advancing corn phenology is the primary factor resulting in oviposition in soybean. We concluded with a review of experiments conducted during the 2001 growing season to test this corn phenology model.

## RESULTS FROM RESEARCH AT MICHIGAN

Recent reports of injury to rotated corn in southwestern Michigan (DiFonzo, 1998) suggest that injury to rotated corn may be spreading into Michigan, as predicted by Onstad et al. (1999). During past 2 yr, we worked with a broad volunteer base to monitor soybean fields throughout lower Michigan by using the scouting and threshold

method developed by O'Neal et al. (2001a). As part of this effort, we tested a behavioral assay to investigate the phenomenon of increased feeding on soybean foliage by variant western corn rootworm.

### Survey of Western Corn Rootworm in Michigan

During summer 1999, volunteers (growers, scouts, and extension agents) monitored 61 fields in a 25-county area, placing four Pherocon AM yellow sticky traps per soybean field for a 2-mo period. Traps were replaced each week and returned to Michigan State University where the number of adult rootworms was counted. Our 1999 survey found very few western corn rootworm in Michigan soybean fields, except for a single field in Clinton County (Figure 1). During spring 2000, we evaluated the extent to which western corn rootworm had oviposited in this site by establishing replicated check strips (corn planted without a soil insecticide, 8-row by 400-m-long strips) in the otherwise treated field.

On 15 July, we compared the rootworm injury of the treated and untreated areas (10 roots per replication, 4 replications per treatment) by using the Iowa State 1-6 scale (Hills and Peters, 1971). In addition, we monitored adult emergence from the rotated cornfield, to further establish whether egg-laying had occurred in the soybean field. We constructed emergence cages that fit over the base of the plant, based on the designs from the Illinois Natural History Survey (Champaign, IL), allowing us to collect adult rootworms from individual plants in the field. We monitored emergence in this rotated cornfield, as well as an adjacent continuous cornfield with 40 traps per field.

In 2000, at the Clinton County site, we found no difference in the mean injury to rotated corn planted with ($1.06 \pm 0.02$ mean root rating) or without ($1.29 \pm 0.06$ mean root rating) a soil insecticide. Although injury was minor, we did collect adult western corn rootworm emerging from the rotated cornfield. However, more western corn rootworm emerged from an adjacent field that had been continuously planted to corn for 4 yr. The peak western corn rootworm emergence in the rotated cornfield was a week later than that of the continuous cornfield. Although preliminary, we consider it interesting that western corn rootworm emerged from a rotated cornfield far from the predicted geographic range of variant western corn rootworm (Onstad et al., 1999) and that this emergence was delayed in comparison with a continuous cornfield. In Illinois and Indiana, areas where crop rotation failures are common, reports of delays in western corn rootworm emergence (Edwards et al., 1997; Shaw et al., 1997) and the latest egg-hatch in >15 yr have been recorded (Edwards, 1997). It is not known whether western corn rootworm emerge later from rotated than continuous cornfields, or from regions where crop rotation failures are common. However, if this trend is consistent, these later emerging adult western corn rootworm would more likely encounter corn in a later phenological stage and thus be more likely to disperse in search of younger corn that is more attractive as a feeding site (Hill and Mayo, 1974; Metcalf, 1986; Naranjo and Sawyer, 1988). If variant western corn rootworm emerged later than the wild type, they would encounter corn in a later phenological stage, and therefore be more likely to disperse from corn. In a landscape planted almost solely to corn and soybean, such as that of east central Illinois, a delay in emergence also would be expected to increase dispersal into soybean.

### Western Corn Rootworm Feeding on Soybean

Both Sammons et al. (1997) and Spencer et al. (1999) observed suspected variant western corn rootworm adults feeding on soybean leaves. Specifically, Sammons et al. (1997) reported that suspected variant beetles from Indiana fed more on soybean leaves in a no-choice assay than putative wild-type western corn rootworm from Iowa and Nebraska, both regions where rotation failures have not been reported. They found that beetles from Nebraska did not feed on soybean leaves. Spencer et al. (1999) reported field observations from Illinois of western corn rootworm feeding on soybean. Spencer et al. (1999) suggested that although a preference for soybean is not necessary to explain rootworm oviposition in soybean, it may be possible to identify beetles that have oviposited in soybean by the presence of soybean foliage in their digestive tract.

In 1999 we conducted both choice and no-choice assays to determine whether feeding behavior could differentiate wild-type from variant western corn rootworm (O'Neal et al., 2001b). We first evaluated whether western corn rootworm adults from different geographical regions varied in their consumption of soybean in no-choice assays patterned after those of Sammons et al. (1997). Based on the results of these no-choice assays, we rejected the hypothesis that variant western corn rootworm (Illinois) consume a greater amount of soybean foliage than wild-type western corn rootworm (Nebraska). Rather, we consistently observed that all western corn rootworm tested consumed soybean foliage, regardless of source population.

Results from the no-choice test led us to study western corn rootworm preference for soybean in the presence of corn at different phenological stages (O'Neal et al., 2001b). We first determined whether corn phenology influenced feeding by western corn rootworm on corn

leaves. In choice tests, we observed that leaves from corn in the early to mid-vegetative (V6-V7) stages were fed on more than leaves in the late vegetative (V10) to reproductive stages (R1-R3). We then constructed a corn-soybean choice assay to determine what effect differing corn phenology may have on the acceptance of soybean as an alternative host. Because western corn rootworm feeding on corn silks is more common than feeding on leaves, we also tested whether soybean leaf feeding occurs only in presence of corn foliage and not in the presence of corn silks. Using western corn rootworm from Michigan cornfields, we predicted that western corn rootworm would feed more on soybean leaves when offered with corn in late vegetative to reproductive stages than with corn in early vegetative stage. As predicted, the soybean leaves offered with the older corn leaves were fed on more than soybean leaves offered with the younger leaves. Although western corn rootworm fed less on soybean leaves when corn silks were offered instead of corn leaves, feeding on soybean leaves still occurred in the presence of silks. In addition, a phenological effect remained when the silks came from older plants (i.e., more soybean leaf area was eaten).

Finally, we investigated whether the phenomenon of corn phenology influencing western corn rootworm feeding on soybean is unique for western corn rootworm from putative variant (Illinois) and wild-type (Nebraska) populations (O'Neal et al., 2001b). Both Illinois and Nebraska beetles fed almost exclusively on corn in the vegetative stage rejecting corn in the reproductive stage. Also, Illinois and Nebraska beetles tended to feed more on soybean in the presence of older corn leaves. Therefore, we conclude that the influence of corn phenology on soybean feeding is common to western corn rootworm throughout the states tested.

## PHENOLOGY-MEDIATED DISPERSAL: CORN PHENOLOGY MODEL FOR ROTATION-RESISTANT WESTERN CORN ROOTWORM

### Western Corn Rootworm and Corn Phenology

The seasonal development (phenology) of corn has been previously shown to influence northern corn rootworm dispersal (Naranjo and Sawyer, 1988) and is thought to have a similar affect on western corn rootworm movement (Naranjo, 1991), but what role it plays in western corn rootworm movement into soybean has not been investigated. Western corn rootworm, especially females with mature eggs, have been observed to move from fields where they emerge and enter rotated cornfields (Godfrey and Turpin, 1983). Like most *Diabrotica*, western corn rootworm prefer to feed on floral parts (Krysan, 1986), and floral volatiles from these parts have been shown to be highly attractive (Metcalf, 1986). It is also well known that later-planted (phenologically young) corn, which flowers later than surrounding cornfields, can function as a trap crop drawing in large numbers of adult corn rootworms (Hill and Mayo, 1974; Naranjo and Sawyer, 1988). These observations suggest western corn rootworm commonly move in and between cornfields in a crop-landscape seeking plants of the most favorable phenological stage.

### Corn Phenology and Failure of Crop Rotation

We found that western corn rootworm feeding on corn leaves is highly influenced by the phenological stage of the plant, and that reduced acceptability of corn influences western corn rootworm feeding on soybean (O'Neal et al., 2001b). We suggest that the larger numbers of western corn rootworm found in soybean than cornfields, as observed by O'Neal et al. (1999), is due primarily to dispersal from cornfields whose phenology no longer makes the crop an attractive feeding site. We suggest that in regions of extensive corn-soybean rotation, corn phenology is responsible for the greater occurrence of western corn rootworm in soybean, and postulate that oviposition occurs coincidentally while adults visit soybean fields. We refer to this phenomenon as the corn phenology model. A prediction from this model is that advancing corn phenology should result in increased western corn rootworm dispersal. The corn phenology model suggests western corn rootworm survival in a corn-soybean-rotated landscape is possible without an attraction to or preference to feed on soybean. This hypothesis may help explain the occurrence of damage to first year corn in northeastern Iowa (Rice and Tollefson, 1999) and central Michigan (Figure 1), areas well outside the predicted range of the variant western corn rootworm (Onstad et al., 1999).

The spread of injury to rotated corn, originating in east central Illinois, is consistent with the diffusion of a genetic change in western corn rootworm behavior (Onstad et al., 1999). Western corn rootworm that oviposit in soybean have a selective advantage because their offspring have a higher probability of survival, and thus selection could produce a variant. Sammons et al. (1997) suggested that a variant would have an increased affinity for soybean. Spencer et al. (1999) refuted this idea, suggesting that survival in a corn-soybean-rotated landscape does not require an attraction to soybean, but rather decreased fidelity to corn. By combining the

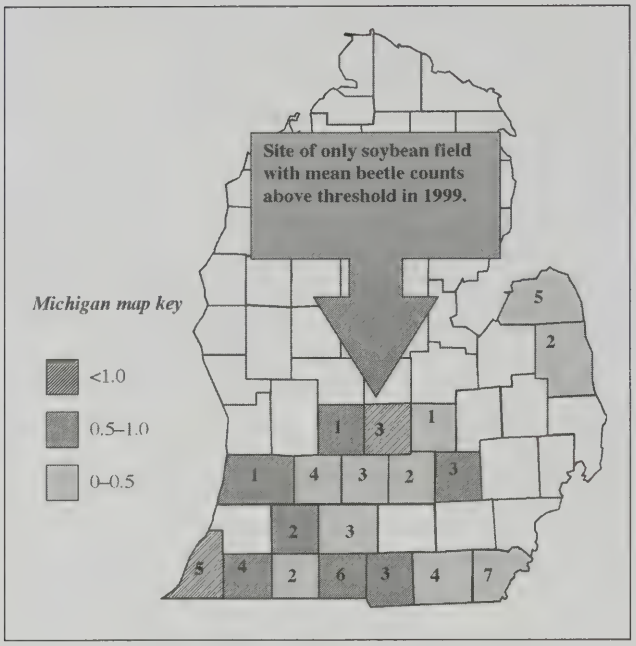



**Figure 1. 1999 distribution of western corn rootworm in soybean fields. Mean beetles/trap/day/field indicates fields monitored per county.**

Spencer et al. (1999) explanation with the corn phenology model, we suggest that dispersal from corn, mediated by corn phenology, is likely to be the primary behavior selected for in a corn-soybean-rotated landscape. Given that we observed corn phenology influencing soybean feeding by western corn rootworm from areas where corn-soybean rotation has failed to protect corn, western corn rootworm response to corn phenology would predate the selection of a rotation-resistant variant. Adult western corn rootworm that respond to corn phenology in a corn-soybean landscape would increase wild-type western corn rootworm oviposition in soybean as less time is spent in the aging corn. Over time, this response would select for western corn rootworm that can survive in a landscape composed of rotated corn and soybean.

Two unique mechanisms could produced a variant whose response to corn phenology is greater than that of the wild type. The first mechanism is physiological, with variant adult western corn rootworm emerging later than the wild type. The second would be a behavioral mechanism that manifests as an increased sensitivity to corn phenology, leading to a decreased fidelity to corn. In the field, the first mechanism would produce the same effect as a decreased fidelity to corn, because later emerging variants would encounter corn in an advanced phenological stage. This second, behavioral mechanism is not mutually exclusive of the physiological-based mechanism. Therefore, to characterize a variant that is resistant to a corn-soybean rotation, we are examining physiological differences (i.e., time to adult emergence) and behavioral (i.e., sensitivity to corn phenology) differences that would produce a greater response to corn phenology in a variant than the wild type.

Our objectives during the summer of 2001 were as follows:

1) Compare adult western corn rootworm emergence in rotated versus continuous cornfields.

2) Measure western corn rootworm dispersal on corn plants of varying phenologies by using a laboratory dispersal assay.

Results from 2001: Testing the Corn Phenology Model

### Emergence Cage Results

To determine whether adult rootworm emergence differed between rotated and continuous cornfields, we selected rotated and continuous cornfields that were planted within 2 d of each other. We identified two "on-farm" sites with adjacent rotated and continuous cornfields in southwestern Michigan and on site in northwestern Indiana. At these sites, we deployed 20 emergence cages per field. Emergence cages were sampled every 3–4 d throughout July and August.

In Figure 2, we report the total number of beetles that emerged in the continuous and rotated cornfields at each site, including the Clinton County field monitored in 2000. The ratio of western corn rootworm emerging between the rotated and continuous cornfields in northwestern Indiana was not significantly different from a 1:1 ratio ($P = 0.07$). In contrast, the number of beetles emerging from the rotated field was a small fraction of those emerging from the continuous cornfield for the three sites in Michigan (Figure 2). That the Indiana site is different is expected, given that this site is considered on the outer edge of the region in Indiana where crop rotation failures are common.

Although western corn rootworm emergence in Indiana suggests that this population is capable of using soybean as an oviposition site, we did not see a delay in emergence in the rotated cornfield (Figure 3), suggesting that a difference between variant and wild-type adult emergence may not exist. However, we do not have a means to confirm that beetles emerging in any field are variant western corn rootworm. The recent announcement of a potential genetic marker for variant western corn rootworm may greatly assist in determining the actual timing of variant emergence. This study will be continued in 2002.

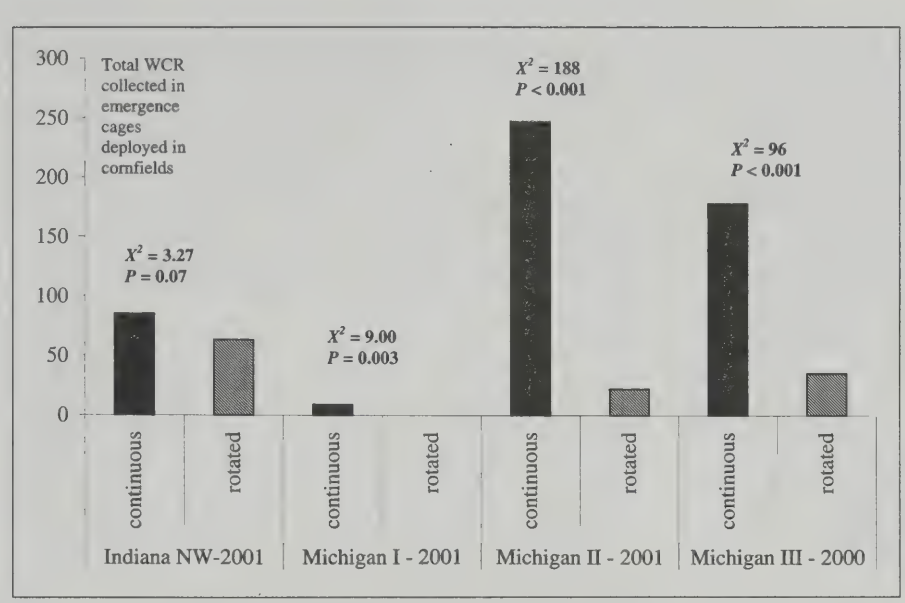



**Figure 2. Western corn rootworm (WCR) emergence as collected in 20 cages per field from adjacent rotated and continuous cornfields.**

Based on preliminary results from spring 2001, we observed greater dispersal from reproductive-stage corn leaves than the sham ($\chi^2$ = 15.69, df = 1, $P$ = 0.001) and from vegetative-stage corn leaves than the sham ($\chi^2$ = 21.17, df = 1, $P$ = 0.001). Although nearly twice as much leaf area was eaten from vegetative than reproductive corn leaves and fewer western corn rootworm remained on reproductive corn after 24 h, there was no significant difference in beetle retention between the two stages ($\chi^2$ = 0.66, df = 1, $P$ = 0.41). However, there were more western corn rootworm ($\chi^2$ = 11.64, df = 1, $P$ = 0.001) retained on tassels shedding pollen (VT-R1 stage) than those no longer producing pollen (R2 stage).

## Dispersal Cage Results

The no-choice dispersal assay is designed to measure western corn rootworm flight dispersal in response to corn of differing phenologies. The design of the dispersal assay is outlined in Figure 4. The inner chamber is constructed so that beetles can be kept within the proximity of the corn organ (leaf, tassels, silks) being tested. In the center of the inner chamber is a 50-ml Erlenmeyer flask filled with distilled water and the corn organ being tested. When testing corn leaves we used a paper leaf mimic as a control. After the lid to the inner chamber is removed, beetles may exit from the inner chamber into the outer chamber. A 10-cm plastic barrier painted with Fluon (Northeast Chemical Co., Woonsocket, RI) prevents beetles from entering the top chamber by simply walking up the outer chamber walls.

After being chilled and separated by sex, 10 western corn rootworm adults are placed within the inner chamber. Assay chambers are kept inside a growth chamber for 24 h (27°C, photoperiod of 16:8 [L:D] h). After the end of 30 min, 3 h, and 24 h, we recorded the number of beetles that remained in the inner chamber. Flight activity of western corn rootworm is considered diurnal (Witkowski et al., 1975), with the greatest amount of immigration to soybean fields occurring during the mid-morning and early evening hours (Isard et al., 2000). All assays were begun in the afternoon, so beetles experienced a full diurnal cycle within the assay chamber.

Based on our spring results, we investigated whether corn phenology-influenced dispersal from corn differed for western corn rootworm from putative variant (Illinois) and wild-type (Nebraska) populations. We used western

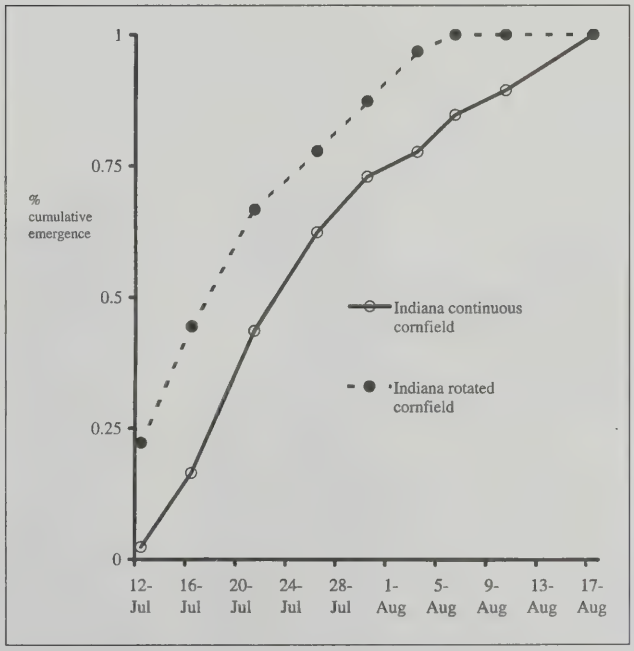



**Figure 3. Percentage of cumulative emergence of western corn rootworm emerging during 2001 growing season from adjacent rotated and continuous cornfields in northwestern Indiana.**

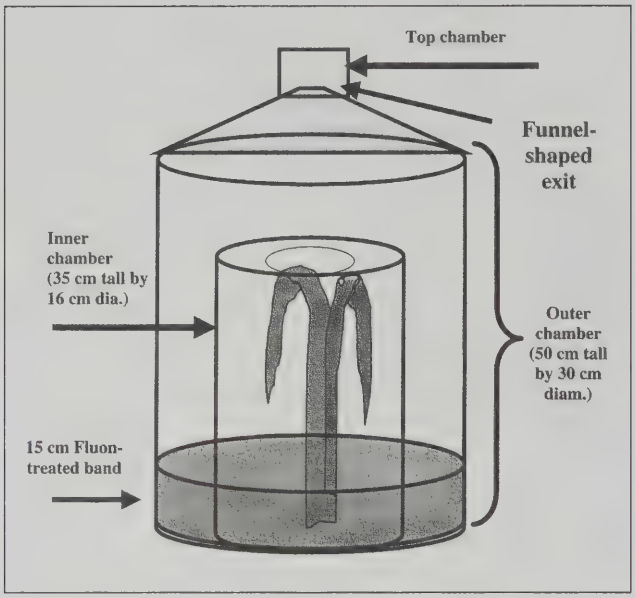

Top chamber
Funnel-shaped exit
Inner chamber (35 cm tall by 16 cm dia.)
Outer chamber (50 cm tall by 30 cm diam.)
15 cm Fluon-treated band

**Figure 4. Schematic of a no-choice dispersal assay. Fluon applied in a 5-cm-high band on the chamber bottom prevents beetles from climbing into top chamber. Beetles must fly from leaves or straight to exit hole to leave inner chamber.Figure 5. Adult western corn rootworm (WCR) dispersal off of corn tassels as measured in a no-choice assay.**

corn rootworm collected from the same sites as our feeding assays, and presented them with tassels with (young tassels) or without (old tassels) pollen. As we saw in the spring, retention on the older tassels was lower than that of the younger tassels (Figure 5; $F = 19.36$; df = 1,7; $P = 0.001$). However, western corn rootworm from Illinois and Nebraska did not differ in their response to either the old or young tassels (Figure 5; $F = 0.89$; df = 1,7; $P = 0.36$).

Our results with the no-choice assay suggest that corn phenology can influence how long western corn rootworm will remain on a corn plant. This response was not unique to western corn rootworm considered to be likely to lay eggs in soybean. We will continue to test what role phenology-mediated dispersal plays in the failure of crop rotation. Future research will investigate whether nutritional status affects western corn rootworm response to corn phenology and whether dispersal to soybean is more likely when western corn rootworm have experienced older rather than younger corn.

## SUMMARY

We conclude that adult western corn rootworm feeding on soybean per se is not a reliable predictor of potential

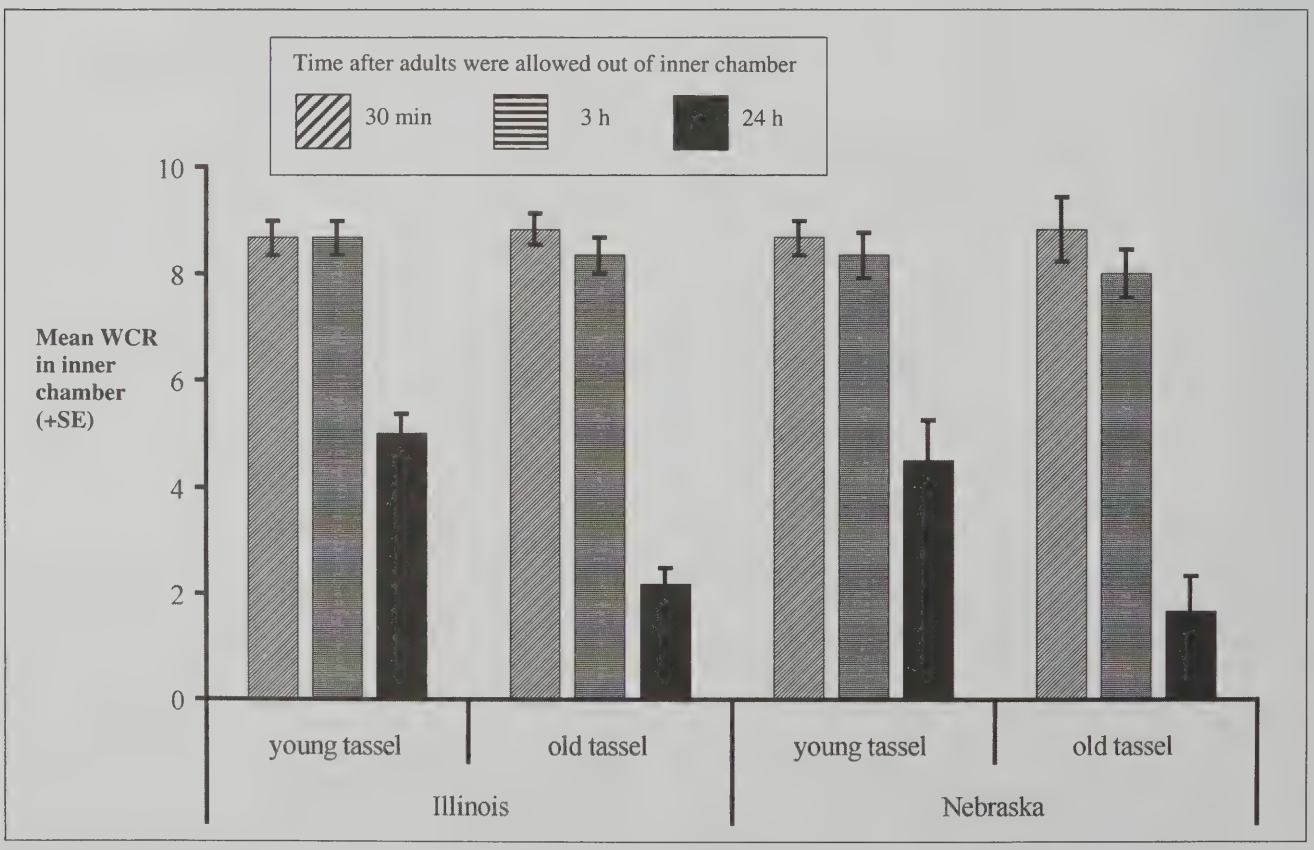



**Figure 5. Adult western corn rootworm (WCR) dispersal off of corn tassels as measured in a no-choice assay.**

oviposition in soybean, because this behavior was not unique to western corn rootworm from areas where corn-soybean rotation fails to protect corn from western corn rootworm larval injury. Rather, we found that western corn rootworm feeding on corn leaves is highly influenced by the phenological stage of the plant, and that reduced acceptability of corn influences western corn rootworm feeding on soybean. We suggest that in regions of extensive corn-soybean rotation, corn phenology is responsible for the greater occurrence of western corn rootworm in soybean, and postulate that oviposition occurs coincidentally while adults visit soybean fields. The advanced development of corn when adult western corn rootworms emerge in a corn-soybean landscape would increase western corn rootworm oviposition in soybean because less time is spent in the aging corn. To identify a variant that is resistant to a corn-soybean rotation, we have begun examining physiological (i.e., adult emergence) or behavioral differences (i.e., sensitivity to corn phenology) that would produce a greater response to corn phenology in a variant than the wild type. Although we are unable to separate variant from wild-type western corn rootworm based on our no-choice dispersal assay, we have observed an increase in dispersal when western corn rootworm are offered older corn. For 2002, we will build on this finding and those of our emergence cage study to further understand how corn phenology impacts western corn rootworm movement and oviposition in soybean.

## ACKNOWLEDGEMENTS

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## REFERENCES

DiFonzo, C.D. 1998. Special Corn Rootworm Issue. Michigan State University Extension, Crop Advisory Team Alert, 13: 12.

Edwards, R. 1997. First hatch of rootworm larvae observed in northwestern Indiana. Pest management and crop production newsletter 13: 2. Purdue Cooperative Extension Service, Purdue University, West Lafayette, IN.

Edwards, R., J. Obermeyer, L. Bledsoe. 1997. Rootworm hatch delayed due to cool soil temperatures, watch for larval activity in treated and untreated fields. Pest management and crop production newsletter 12: 1-2. Purdue Cooperative Extension Service, Purdue University, West Lafayette, IN.

Godfrey, L.D. and F.T. Turpin. 1983. Comparison of western corn rootworm (Coleoptera: Chrysomelidae) adult populations and economic thresholds in first-year and continuous cornfields. *Journal of Economic Entomology* 76: 1028-1032.

Hein, G.L. and J.J. Tollefson. 1985. Seasonal oviposition of northern and western corn rootworms (Coleoptera: Chrysomelidae) in continuous cornfields. *Journal of Economic Entomology* 78: 1238-1241.

Hill, R.E. and Z B Mayo. 1974. Trap-corn to control corn rootworms. *Journal of Economic Entomology* 67: 748-750.

Hills, T.M., and D.C. Peters. 1971. A method of evaluating postplant insecticide treatments for control of western corn rootworm larvae. *Journal of Economic Entomology* 64: 764-765.

Isard, S.A., J.L. Spencer, M.A. Nassar, and E. Levine. 2000. Aerial movement of western corn rootworm (Coleoptera: Chrysomelidae): diel periodicity of flight activity in soybean fields. *Environmental Entomology* 29: 226-235.

Krysan, J.L. 1986. Introduction: biology, distribution, and identification of pest *Diabrotica*, in Methods for the Study of Pest *Diabrotica* (J.L. Krysan and T.A. Miller eds) pp 1-23, Springer Verlag, New York.

Levine, E. and M.E. Gray. 1996. First-year corn rootworm injury: east central Illinois research progress to date and recommendations for 1996, in *Proceedings of the 1996 Illinois Agricultural Pesticides Conference*, pp 3-13. Cooperative Extension Service, University of Illinois at Urbana-Champaign, January 8-9.

Levine, E., and H. Oloumi-Sadeghi. 1996. Western corn rootworm (Coleoptera: Chrysomelidae) larval injury to corn grown for seed production following soybeans grown for seed production. *Journal of Economic Entomology* 89: 1010-1016.

Metcalf, R. L.1986. Plant volatiles as insect attractants. *CRC Critical Reviews in Plant Science* 5: 251-301.

Naranjo, S.E. 1991. Movement of corn rootworm beetles, *Diabrotica* spp. (Coleoptera: Chrysomelidae), at cornfield boundaries in relation to sex, reproductive status and crop phenology. *Environmental Entomology* 20: 230-240.

Naranjo, S.E. and A.J. Sawyer. 1988. A simulation model of northern corn rootworm, *Diabrotica barberi* Smith & Lawrence (Coleoptera: Chrysomelidae), in field corn. *Environmental Entomology* 17: 508-521.

O'Neal, M.E., C. DiFonzo, and D. Landis. 2001a. Western corn rootworm (Coleoptera: Chrysomelidae) feeding on corn and soybean leaves is influenced by corn phenology. *Environmental Entomology* (in press).

O'Neal, M.E., M.E. Gray, and C. Smyth. 1999. Population characteristics of a western corn rootworm (Coleoptera: Chrysomelidae) strain in east-central Illinois corn and soybean fields. *Journal of Economic Entomology* 92: 1301-1310.

O'Neal, M.E., M.E. Gray, K. Steffey, and S. Ratcliffe. 2001b. Economic threshold for western corn rootworm (Coleoptera: Chrysomelidae) captured in soybeans for the protection of rotated corn. *Journal of Economic Entomology* 93 (in press).

Onstad, D.W., M.G. Joselyn, S.A. Isard, E. Levine, J.L. Spencer, L.W. Bledsoe, C.R. Edwards, C.D. DiFonzo, and H. Willson. 1999. Modeling the spread of western corn rootworm (Coleoptera: Chrysomelidae) populations adapting to soybean-corn rotation. *Environmental Entomology* 28: 188-194.

Rice, M.E. and J. Tollefson. 1999. Corn rootworms and lodged first-year corn. Iowa State University Extension, Integrated Crop Management IC-482(22).

Sammons, A.E., C.R. Edwards, L.W. Bledsoe, P.J. Boeve, and J.J. Stuart. 1997. Behavioral and feeding assays reveal a western corn rootworm (Coleoptera: Chrysomelidae) variant that is attracted to soybean. *Environmental Entomology* 26: 1336-1342.

Shaw J., K. Steffey, M. Gray, and J. Finger. 1997. Delayed corn rootworm egg hatch and rootworm pressure: what did our root rating evaluations reveal? in *Proceedings, Illinois Agricultural Pesticides Conference*, pp 93-95, Cooperative Extension Service, University of Illinois at Urbana-Champaign.

Spencer J.L., S.A. Isard, and E. Levine. 1999. Free flight of western corn rootworm (Coleoptera: Chrysomelidae) to corn and soybean plants in a walk-in wind tunnel. *Journal of Economic Entomology* 92: 146-155.

Witkowski, J.F., J.G. Owens, and J.J. Tollefson. 1975. Diel activity and vertical flight distribution of adult western corn rootworms in Iowa cornfields. *Journal of Economic Entomology* 68: 351-352.

SERVING AGRICULTURE AND THE ENVIRONMENT

PROCEEDINGS

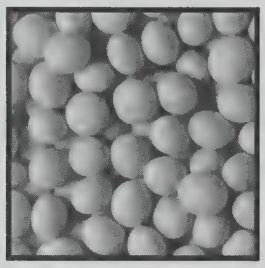
# ILLINOIS CROP PROTECTION TECHNOLOGY CONFERENCE

JANUARY 7 & 8, 2003

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

UNIVERSITY OF ILLINOIS EXTENSION
COLLEGE OF AGRICULTURAL, CONSUMER AND ENVIRONMENTAL SCIENCES
IN COOPERATION WITH
THE OFFICE OF CONTINUING EDUCATION
DIVISION OF CONFERENCES & INSTITUTES

SERVING AGRICULTURE AND THE ENVIRONMENT



PROCEEDINGS

# ILLINOIS CROP PROTECTION TECHNOLOGY CONFERENCE

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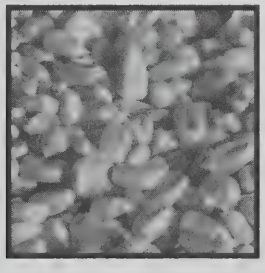

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Dean E. Riechers

# 2003 ILLINOIS CROP PROTECTION TECHNOLOGY CONFERENCE PLANNING COMMITTEE

## Co-Chairs:

**Suzanne Bissonnette**
Champaign Extension Center
University of Illinois Extension

**Michael Gray**
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University of Illinois

**Bruce Paulsrud**
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**Christy Sprague**
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**Elaine Wolff**
Conferences & Institutes
University of Illinois

## Other Committee Members:

**Steve Barrett**
Galesville Chemical Co.

**Kevin Black**
GROWMARK, Inc.

**George Czapar**
Springfield Extension Center
University of Illinois Extension

**John Foster**
Pine Incorporated

**Aaron Hager**
Department of Crop Sciences
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**Al Hansen**
Department of Agricultural Engineering
University of Illinois

**Gerald Kirbach**
Illinois Department of Agriculture

**Dean Malvick**
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**Sandy Osterbur**
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**Mike Rahe**
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**A.G. Taylor**
Illinois Environmental Protection Agency

**Sarah Taylor-Lovell**
Dow AgroSciences

**Dave Thomas**
Syngenta Crop Protection

**Rob Wynstra**
Information Technology and
Communication Services
University of Illinois

**Dan Zinck**
Monsanto

# PROGRAM – JANUARY 7 & 8, 2003

## Tuesday Morning, January 7

| | |
|---|---|
| 9:00 AM | Welcome and Opening Remarks – Illini Rooms A, B, C, *Suzanne Bissonnette* |

**Keynote Session: Homeland Security and Ag Bio-Terrorism** (0.5 CCA credit in Pest Management)
*Todd Gleason, Moderator*

| | |
|---|---|
| 9:15 AM | Integrated Food and Ag-Biosecurity Command and Control Concept, *Dennis Andersh* |
| 9:45 AM | Homeland Security in Illinois: An Agenda, *Richard Jaehne* |
| 10:15 AM | Break |
| 10:30 AM | Decision Making in Times of Uncertain Crises: Consumers' Risk Attitudes & Risk Perceptions, *Joost Pennings* |
| 11:00 AM | National Plant Pest and Disease Network: Increased Vigilance for Agricultural Security, *Kitty Cardwell* |
| 11:30 AM | Questions |
| 11:45 AM – 1:00 PM | Lunch |

## Tuesday Afternoon, January 7

**Symposia A and B run concurrently with Seminars 1–5 from 1:00–2:30 PM**

**Symposium A: Environmental Stewardship and Spray Drift** – Illini Room A
(1.0 CCA credit in Pest Management)
*Gerald Kirbach and Al Hansen, Moderators*

| | |
|---|---|
| 1:00 PM | The Real Cost of Spray Claims, *Michael Smith* |
| 1:25 PM | Deciding Your Future, *Loren Bode* |
| 1:50 PM | Drift Reduction Strategies, *Mark Mohr* |
| 2:15 PM | Panel Discussion |

**Symposium B: Invasive Species** – Illini Room B
(1.5 CCA credits in Pest Management)
*Kevin Black and Dean Malvick, Moderators*

| | |
|---|---|
| 1:00 PM | Soybean Rust: Past, Present, and Future, *Glen Hartman* |
| 1:20 PM | Current and Future Prospects for Biological Control of Invasive Weeds in Illinois, *Robert Wiedenmann* |
| 1:40 PM | West Nile Virus: an IPM Challenge in Illinois, *Robert Novak* |
| 2:00 PM | Gathering Storm or Dissipating Threat? Status, Prognosis, and Management of the Soybean Aphid, *Ken Ostlie* |
| 2:20 PM | Panel Discussion |

**Seminars 1–5 run concurrently with Symposia A and B from 1:00–2:30 PM**

**Seminar 1: Conflict . . . An Opportunity for Development** – Room 405 – *Anne Silvis and Ben Mueller*

Believe it or not, conflict is an opportunity for development. The opportunity lies in managing difficult situations to create some good from the energy, interest, and emotion that people bring to the conflict. This workshop will help you better understand the conflict cycle, provide some strategies for managing conflict, and give you a chance to practice analyzing conflict and working to resolve it. It is unrealistic to expect that our lives will be free of conflict, but it is realistic to learn how to manage conflict to minimize the negative consequences and maximize the positive outcomes.

**Seminar 2: Economics of Site-Specific Management** – Room 407 – *James Lowenberg-DeBoer*

This presentation will focus on who is using precision agriculture technology and how profitably. Examples will be drawn from research on site-specific soil fertility management, GPS guidance, and variable rate planting. (1.5 CCA credits in Crop Management)

**Seminar 3: Biology and Control of Selected Problem Weeds** – Room 314B – *William Curran*

Changes in the weed spectrum frequently lead to additional management difficulties. These changes may be caused by the presence of weed species not previously considered problematic, changes in management practices, or changes in the biology of more familiar species. This session will discuss a number of weeds of concern including burcucumber and glyphosate-

esistant horseweed (marestail), which is making its vay westward into the Midwest. (1.5 CCA credits in Pest Management)

**Seminar 4: Aquatic Weed Management** – Room 404 – *George Czapar*

Weed control in aquatic environments can often be difficult. Balancing the correct amount vegetative growth is important to keep aquatic eco-systems healthy. This session will focus on identification and management of algae and weeds in aquatic situations. (1.5 CCA credits in Pest Management)

**Seminar 5: Earthworms and Soil Management Practices** – Room 314A – *Eileen Kladivko*

This presentation will provide basic information on earthworm ecology, the effects of earthworms on soil properties and processes, and the influence of soil management practices on earthworms. The effects of tillage practices and pesticide and fertilizer use will be discussed, as well as preliminary observations on water table management practices compared with standard tile drainage. The potential practical significance of earthworms in Midwestern row crop fields will be presented, along with general guidelines for increasing earthworm populations and activity. (1.5 CCA credits in Soil and Water Management)

2:30–3:00 PM Break – Illini Room C and Room 406

**Symposia A and B and Seminars 1–5 repeated concurrently from 3:00–4:30 PM**

**Symposium A (repeated): Environmental Stewardship and Spray Drift** – Illini Room A

**Symposium B (repeated): Invasive Species** – Illini Room B

**Seminar 1 (repeated): Conflict . . . An Opportunity for Development** – Room 405

**Seminar 2 (repeated): Economics of Site-Specific Management** – Room 407

**Seminar 3 (repeated): Biology and Control of Selected Problem Weeds** – Room 314B

**Seminar 4 (repeated): Aquatic Weed Management** – Room 404

**Seminar 5 (repeated): Earthworms and Soil Management Practices** – Room 314A

4:30–6:30 PM **IFCA-Sponsored Mixer** – Illini Union Ballroom, 2nd floor

This mixer is sponsored by the Illinois Fertilizer and Chemical Association. It is intended for everyone to meet with speakers, sponsors, and committee members in an informal atmosphere.

## Wednesday Morning, January 8

**Symposia C and D run concurrently with Seminars 6–10 from 8:00–9:30 AM**

**Symposium C: Improving Water Quality and Natural Resources** – Illini Room A
(1.5 CCA credits in Soil and Water Management)
*George Czapar and A.G. Taylor, Moderators*

| | |
|---|---|
| 8:00 AM | Nutrient Management Challenges, *Dennis McKenna* |
| 8:20 AM | Pollywogs, Pesticides, and Parasites, *Allan Felsot* |
| 8:40 AM | Status of Illinois Streams and Inland Lakes, 305(b) Report, *Gregg Good* |
| 9:00 AM | On-Farm Containment and Other State Regulatory Changes for 2003, *Warren Goetsch* |
| 9:20 AM | Panel Discussion |

**Symposium D: Key Pest and Crop Management Issues** – Illini Room B
(1.0 CCA credit in Pest Management)
*Dave Thomas and Michael Gray, Moderators*

| | |
|---|---|
| 8:00 AM | Japanese Beetles and Western Corn Rootworms: Old Insect Foes Present New Challenges, *Michael Gray* |
| 8:20 AM | Plant Disease Issues from 2002, *Darin Eastburn* |
| 8:40 AM | Weed Management Challenges from 2002, *Aaron Hager and Christy Sprague* |
| 9:00 AM | Crop Management Issues from 2002, *Emerson Nafziger* |
| 9:20 AM | Panel Discussion |

**Seminars 6–10 run concurrently with Symposia C and D from 8:00–9:30 AM**

**Seminar 6: Disease Interactions: SCN, SDS, and BSR: What's Going On Here?** – Room 407 – *Terry Niblack and Dean Malvick*

The soybean cyst nematode (SCN) reduces soybean yield all by itself, but it can also make it more likely that other yield-reducing diseases of soybean will show up, such as sudden death syndrome (SDS) and brown stem rot (BSR). Management of these diseases depends on knowledge of the control options and good diagnostic skills. (1.5 CCA credits in Pest Management)

**Seminar 7: Stress and the Common Corn Plant** – Room 314A – *Bob Nielsen*

The spring of 2002 was cool and wet and delayed corn planting in many areas of Illinois. The spring was followed by very hot and dry growing conditions in many parts of the Corn Belt. This seminar will focus on the growth and development of corn as affected by environmental stresses. Come ready to raise questions and engage in an active discussion. (1.5 CCA credits in Crop Management)

**Seminar 8: Managing Birds, Deer, and Small Rodents in the Field** – Room 404 – *Ron Hines and John Pickle*

Research results on bird, deer, and small rodent damage prevention in corn and soybean will be highlighted. Current application equipment and labeled damage prevention products will also be discussed. (1.5 CCA credits in Pest Management)

**Seminar 9: Getting It Right the First Time: Calibrating Field Sprayers** – Room 314B – *Mark Mohr and Bob Wolf*

Application errors can be costly and time-consuming; but, most importantly, they can be prevented. A successful professional applicator needs to be able to prevent problems or to immediately correct problems that do occur, which means understanding the basic workings of a modern sprayer. This seminar will cover some of the fundamentals of application, including pesticide math, nozzle selection, and controller basics. (1.5 CCA credits in Pest Management)

**Seminar 10: Transmission of Bean Pod Mottle Virus in Soybeans by Bean Leaf Beetles and Western Corn Rootworm Adults** – Room 405 – *Eli Levine*

Bean pod mottle virus (BPMV) is a beetle-transmitted viral disease of soybeans which can lower seed quality and yield. The primary vector of BPMV is the bean leaf beetle. The Western corn rootworm is now found in very high numbers in soybean fields in east central Illinois and northern Indiana; adults lay their eggs in these fields and feed on soybean foliage. In case studies, we demonstrated that field-collected western corn rootworm adults were able to transmit BPMV to soybean plants. (1.5 CCA credits in Pest Management)

| | |
|---|---|
| 9:30–10:00 AM | Break – Illini Room C and Room 406 |

**Symposia C and D and Seminars 6–10 repeated concurrently from 10:00–11:30 AM**

**Symposium C (repeated): Improving Water Quality and Natural Resources** – Illini Room A

**Symposium D (repeated): Key Pest and Crop Management Issues** – Illini Room B

**Seminar 6 (repeated): Disease Interactions: SCN, SDS, and BSR: What's Going On Here?** – Room 407

**Seminar 7 (repeated): Stress and the Common Corn Plant** – Room 314A

**Seminar 8 (repeated): Managing Birds, Deer, and Small Rodents in the Field** – Room 404

**Seminar 9 (repeated): Getting It Right the First Time: Calibrating Field Sprayers** – Room 314B

**Seminar 10 (repeated): Transmission of Bean Pod Mottle Virus in Soybeans by Bean Leaf Beetles and Western Corn Rootworm Adults** – Room 405

| | |
|---|---|
| 11:30 AM–1:00 PM | Lunch |

## Wednesday Afternoon, January 8

**Symposia E and F run concurrently with Seminars 11–15 from 1:00–2:30 PM**

**Symposium E: Stewardship of Transgenic Technologies** – Illini Room A
(1.5 CCA credits in Pest Management)
*Sarah Taylor-Lovell and Bruce Paulsrud, Moderators*

| | |
|---|---|
| 1:00 PM | Pollen Drift and Its Impact on Gene Flow between GMO and Non-GMO Cultivars, *Martin Bohn* |
| 1:20 PM | Bt Corn, Refuges, and Monarchs: Challenges for Entomologists and Growers, *Rick Hellmich* |
| 1:40 PM | Integrating Integrated Weed Management into Glyphosate-Resistant Cropping Systems, *Aaron Hager* |
| 2:00 PM | Corn Rootworm Management with Genetically Engineered Corn Hybrids, *Jon Tollefson* |
| 2:20 PM | Panel Discussion |

**Symposium F: New Developments in Crop Protection Products: A University's Perspective** – Illini Room B (1.5 CCA credits in Pest Management)
*Dan Zinck and Christy Sprague, Moderators*

| | |
|---|---|
| 1:00 PM | Product Update in Weed Management, *Christy Sprague* |
| 1:25 PM | Product Update in Insect Management, *Kevin Steffey* |
| 1:50 PM | Product Update in Disease Management, *Dean Malvick* |
| 2:15 PM | Panel Discussion |

**Seminars 11–15 run concurrently with Symposia E and F from 1:00–2:30 PM**

**Seminar 11: Herbicide Fate as Influenced by the Soil Environment** – Room 314A – *Bill Simmons*

Soil-applied herbicides and post-emergence herbicides with soil activity are important parts of weed management systems. Learn how application timing, weather, and soil conditions affect herbicides. What is the potential carryover or crop response to soil-applied herbicides? This session offers a comprehensive review of how current commercially used corn and soybean herbicides behave in the soil. (1.5 CCA credits in Soil and Water Management)

**Seminar 12: Winter Annual Weed Management** – Room 404 – *William G. Johnson and Ryan F. Hasty*

Winter annual weed species have become a significant weed problem in Illinois. This session will focus on identification and control strategies that can be used to manage winter annual weeds. This session will also include the latest results and information on fall herbicide applications for winter annual weed control. (1.5 CCA credits in Pest Management)

**Seminar 13: CSI: Crop Symptom Investigation** – Room 407 – *Dennis Bowman and Dave Feltes*

Diagnosing crop problems requires combining agronomic knowledge with the investigative skills of a crime scene investigator or medical examiner. This workshop will cover how to approach an unusual field condition, examine the evidence, interview the witnesses, and eliminate suspects. (1.5 CCA credits in Pest Management)

**Seminar 14: Drift Reduction Tools and Techniques** – Room 314B – *Mark Mohr and Bob Wolf*

Applicators have many options available when it comes to reducing drift, ranging from nozzle technology to mapping software. Avoiding drift is a critical requirement for successful applicators and is best done by combining up-to-date equipment, a basic understanding of the causes of drift, and a "not on my watch!" state-of-mind. (1.5 CCA credits in Soil and Water Management)

**Seminar 15: Understanding Herbicide Modes of Action: Invaluable in Diagnosing Herbicide Injury and Preventing Resistance Development** – Room 405 – *Dean Riechers*

Herbicide mode of action may be defined as how a herbicide kills a plant. A working knowledge of herbicide mode of action can be beneficial when planning a weed management program. Ideally, a herbicide should provide good weed control without adverse effects on the crop. However, crops are often injured by herbicides. Herbicide safeners are often included with soil-applied herbicides to decrease the occurrence of injury under cool, wet conditions in the spring. This session will discuss the various modes of action and sites of action of herbicides that are commonly used in corn and soybean production. Injury symptoms associated with the herbicide families, and the use of safeners to prevent herbicide injury will be discussed. (1.5 CCA credits in Pest Management)

| | |
|---|---|
| 2:00–2:30 PM | Break – Illini Room C and Room 406 |

**Symposia E and F and Seminars 11–15 repeated concurrently from 3:00–4:30 PM**

**Symposium E (repeated): Stewardship of Transgenic Technologies** – Illini Room A

**Symposium F (repeated): New Developments in Crop Protection Products: A University's Perspective** – Illini Room B

**Seminar 11 (repeated): Herbicide Fate as Influenced by the Soil Environment** – Room 314A

**Seminar 12 (repeated): Winter Annual Weed Management** – Room 404

**Seminar 13 (repeated): CSI: Crop Symptom Investigation** – Room 407

**Seminar 14 (repeated): Drift Reduction Tools and Techniques** – Room 314B

**Seminar 15 (repeated): Understanding Herbicide Modes of Action: Invaluable in Diagnosing Herbicide Injury and Preventing Resistance Development** – Room 405

| | |
|---|---|
| 4:30 PM | Adjourn |

# PROGRAM PARTICIPANTS

**Andersh, Dennis**, Vice President and Operations Manager, SAIC/DEMACO, Champaign, IL

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# HOMELAND SECURITY IN ILLINOIS: AN AGENDA

**Richard L. Jaehne**

Never in the past century have local decisions had greater importance and relevance than they do post-11 September 2001. Over the past 60 years America has repeatedly taken actions at the local community level to affect national security. Prior to 11 September 2001, we have called these actions "civil defense," and "domestic preparedness." In the aftermath of terrorists attacks and threats, both the lexicon and actions taken by state and local governments must be expanded. We must establish a new security paradigm called "homeland security" that provides active prevention and preemption plans and protocols designed to stop terrorist attacks, lessen their effect, and prepare authorities to respond to them. National security will depend upon actions taken by local elected officials, public safety organizations, in schools, businesses and by citizens. They will have a pivotal role in identifying potential threats and providing first response to contain and mitigate their potential effects.

For the past several years, the U.S. has been pursuing a two-pronged strategy for dealing with the threat of terrorism. The first, ***crisis management***, was a law enforcement-focused strategy sponsored through the US Department of Justice that sought to focus law enforcement and intelligence agencies on preventing a terrorist event. The second, ***consequence management***, was a public safety-focused strategy sponsored in part through the Federal Emergency Management Agency, which placed enormous reliance in state and local emergency management, fire service and public health organizations. These strategies viewed terrorism as a national catastrophic event much the same a nuclear attack was viewed in the 1960's and the resulting strategies placed no significant reliance on local authorities to prevent or preempt attacks. They

were even called "weapons of mass destruction (WMD) events."

One of the clear lessons of 11 September is that actions taken locally are critical to protect Americans against terrorism. Terrorism cannot be viewed solely as a strategic national event nor as a problem outside US borders to be combated by national and international defense, diplomatic and intelligence activities. Terrorist events and threats in the U.S. will be local. Local response and recovery plans must be prepared and exercised before a terrorist event and these plans should envision actions that can be taken to prevent or even preempt a terrorist attack.

We need to create a "bridge" of active defense measures between these two concepts that creates open communication and allows for coordinated action. This is the new model for "Homeland Security." The challenge is to create a cohesive homeland security policy from the interagency stewpot of domestic law enforcement, public safety, and elected officials, in a unified way at the local, regional, state, and national level.

## WORK ALREADY UNDERWAY

On May 16, 2000, Governor George Ryan signed Executive Order Number 10, creating the Illinois Terrorism Task Force (ITTF). Under the leadership of the Deputy Governor for Public Safety and Illinois State Director for Homeland Security Matt Bettenhausen and Illinois Emergency Management Agency (IEMA) Director Michael Chamness, the Task Force has provided an on-going interagency forum to develop Homeland Security policies and to direct state efforts toward planning, preparation and response to terrorism in Illinois.

We have coined a term for the elements that we must have to respond to a terrorist incident as B-NICE (Biological, nuclear, incendiary, chemical and explosive). Illinois has built and is continuing to augment its special team capability to deal with these events. Today, through the interagency cooperation of the task force members, Illinois has 3 fully operational State Interagency Response Teams (SIRT) that can respond to a homeland security incident anywhere in Illinois within 60-90 minutes of activation and provide "all avenues of support" to the local incident commander and the appropriate agencies. Illinois has a terrorism training strategy with seven clear objectives, curriculum and instructors in place to reach every first responder statewide. Illinois has identified 32 hazardous material (HAZMAT) level A and B technical teams that can respond anywhere in the state and work together to mitigate nuclear, biological, or chemical contamination and assist with explosive and incendiary devices at a terrorist incident. In addition, special rescue teams, bomb squads, dog teams and other specialized teams that have been organized, trained and equipped at the local, regional and state level have been identified for deployment statewide in case of an emergency. Many of these teams have attended national training. In addition, a county-by-county series of risk assessments were completed in November 01 to establish a federal baseline for Illinois.

Equally important, IEMA has implemented a state inter-agency command and control system to plan and direct support for counter-terrorist response. This system was activated within minutes of the attacks on the World Trade Center and remains active to plan and direct homeland security activities. It is also important that in 2001, for the first time in Illinois history, there is a system for statewide fire service mutual aid. This means that one phone call can coordinate assistance from every fire department to support those departments dealing with an incident. In addition, Governor Ryan requested and in December 2001, the State Legislature approved $17 million in supplemental homeland security fiscal year 2002 funding to augment these activities.

Pro-active leadership is a critical component at every level. To more effectively protect Illinois, each local jurisdiction and public safety entity must be part of the planning, preparation and preemption efforts. Our goal should be to establish a pro-active, integrated, layered, active defense shield against terrorist attack on critical Illinois infrastructure.

The experience garnered by the U.S. and Illinois when dealing with the call for active civil defense in World War II and during the nuclear crisis of 1961-62 indicates that there are three critical components of an effective response. Implementation of Homeland Security post-September 11, 2001 therefore should build on these three components:

1. Creation of a universally understood, integrated, yet flexible early warning system from national through state to local level.
2. Implementation of a broad-based public information campaign to inform each citizen (to include school children) about the terrorist threat and what each can do to help protect against the threat.
3. Creation of a series of small interagency teams that develop and implement specific programs to counter the threat and respond to catastrophic events.

We will consider each of these components in turn.

## EARLY WARNING SYSTEM

To create an early warning system, we need to re-tool and expand the existing early warning system to incorporate terrorist "Threatcon" (threat condition) measures based upon the military Threatcon system. This system should include discrete measures appropriate for local communities and critical Illinois infrastructure. Governor Ridge, the new National Homeland Security Coordinator, has now called for such a system to be established nationwide, to replace the non-descript system of "heightened security alerts" published since 11 September.

A system similar to the existing US military system would define five Threatcon levels defined by the

nature, severity, timing and proximity of the potential terrorist threat. The military Threatcon are:

- **Threatcon normal**—General threat of terrorist activity exists but warrants only a routine security posture.
- **Threatcon Alpha**—General threat of terrorist activity is possible and increased security posture is warranted.
- **Threatcon Bravo**—General threat of terrorist activity is increased and specific threats are predicted.
- **Threatcon Charlie**—A Terrorism incident has occurred or intelligence is received that an attack is imminent.
- **Threatcon Delta**—A terrorist attack has occurred or intelligence indicates that an attack against a specific location is expected—highest security level.

Each of these Threatcons has a series of discrete security measures that should be considered in the development of local protocols. Each jurisdiction would consider the set of recommended measures in the development of their local protocol of measures to implement at each threatcon level. For example, when Threatcon Alpha is acted, the following measures should be considered:

1. Commence periodic public announcements on security precautions.
2. Review all key staffing, emergency staffing and planning documents.
3. Secure buildings, rooms and storage areas.
4. Increase random security spot checks.
5. Limit access points for vehicles and personnel.
6. Consider implementation of selected Threatcon B security measures.
7. Review continuity of government plans and security measures for high risk personnel.

As Threatcon levels increase, the measures expand and focus planning, preparation and preemption activities on the critical issues. Threatcons should be the subject of a broad-based public information effort to engender effective public assistance and respnse and to reduce public fear and panic resulting from terrorist threats or events.

The state should also create Terrorist Early Warning (TEW) Groups that, among other duties, would disseminate intelligence used for setting the Threatcon level. TEWs will be discussed in more detail later.

## PUBLIC INFORMATION CAMPAIGN

A public information effort is underway. Governor Ryan began a series of workshops around the state on October 29, 2001 to kickoff this effort. In addition, the Illinois Terrorism Task Force has formed a subcommittee to address this as an on-going issue.

This campaign must be broad enough in scope to reach all Illinois citizens and special groups, such as school children. A baseline public survey should be conducted to discover citizen perceptions of security, what actions citizens have taken or will take in case of terrorist attack, and what expectations for security they have. With this information in hand, a multimedia campaign that includes paid and public service announcements, as well as tailored products targeted to reach specific groups and to touch on specific themes, should be developed. Follow-up surveys should be done to judge the effectiveness of the campaign and to allow response to changes in citizen perceptions. Local jurisdictions must play an active role in this effort.

Beyond informing the public, Illinois needs to bring leaders at the local, regional and state level together to create a system of ongoing security measures and to define their role in those measures. Local leaders particularly need to support these efforts. To this end a series of Homeland Security Planning Workshops will be held beginning in February through May 2002 culminating in a Statewide Homeland Security Summit on 20-21 May 2002 at the University of Illinois Springfield. *The goal of these workshops is to help local and regional officials plan and identify actions that can be taken at the local and regional levels to improve homeland security against terrorism in Illinois.* The workshops will be a Terrorism Task Force cooperative effort sponsored under a Partnership Illinois grant from the University of Illinois. The workshops will seek to bring together leaders and key decision-makers:

- Elected Officials
- Fire Service
- Law Enforcement
- Emergency management
- Public Health
- Public Services
- Private Sector

- Educators
- Transport
- Federal & national representatives
- Non-government organizations
- State agency reps

For more information visit the Illinois Fire Service Institute website at: http://www.FSI.uiuc.edu.

## INTERAGENCY TEAMS

Traditional civil defense and natural disaster response has four phases: awareness, alert, warning, and response. Homeland Security must add "preemption" between warning and response.

To accomplish all 5 required phases, the Illinois Terrorism Task Force will expand the statewide program for equipping, training and supporting first responders. Beyond this it should strengthen the State's ability to create effective homeland security policy by serving as an inter-agency, public and private policy "think-tank" to assist in developing anti-terrorism policy and plans. Illinois must reinforce its ability to speak with one voice to the multiplicity of federal agencies that control federal homeland security resources and policy. This means modest but permanent staffing and funding for the State Homeland Security Coordinator and Terrorism Task Force.

In 1996, in response to a need for integrated terrorism response, Los Angeles County created a Terrorist Early Warning (TEW) Group to "monitor trends and potentialities that may result in terrorists threats in the County." The unique organization, capabilities and results of the Group were the subject of a special case study contained in the *Second (national) Annual Report of the Advisory Panel to Assess Domestic Response Capabilities for Terrorism Involving Weapons of Mass Destruction.* At least two Terrorist Early Warning Groups should be created in Illinois, one in Chicago for the Chicago metropolitan area and one in Springfield for national-state interface and for the remainder of the state. These groups must include representatives from relevant agencies, including federal, state and local officials, and should be led by law-enforcement officials. They will have three missions: to create an intelligence collection-assessment-production-and dissemination process, to conduct critical targe-threat-capability net assessments, and to conduct joint operational planning and mission direction.

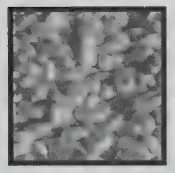
Members of these groups will need to build a critical infrastructure target list (commercial, financial, information and political, etc.) and conduct a threat analysis for each target and each potential type of terrorist attack (cyber + B-Nice, etc.). That analysis can then be used to build critical infrastructure target folders with defense, preemption and response plans and protocols that are available to those involved in preparing for potential attacks.

Regardless of State and Federal action, there must be local planning. Many communities have formed Local Emergency Planning Committees (LEPC). These must be active, robust and fully integrated with interagency homeland defense planning and preparation efforts in local communities. Where no LEPC's exist, they should be created to coordinate regional and local emergency management plans and processes.

Preparation must also include training and practice. Interagency training exercises should be conducted at the local, regional and State level to enhance homeland security command and control, planning and response capabilities. These exercises should focus on unified command processes and training local first responders, as well as members of regional and state agencies, on homeland defense scenarios. Technical experts should be included to help improve these processes.

In developing Illinois' anti-terrorism policy, we must recognize that homeland security will require proactive leadership at every level. Local, regional, State and Federal agencies and decision-makers must build an on-going dialogue, relevant response structures and integrated plans and protocols. We must develop an early warning system that is broadly used and understood. At each level, we must find ways to inform the public in general as well as special groups, such as school children. At each level, we must develop cooperation between agencies so as to ensure that we are prepared to both preempt and react to terrorist activity.

Events of 11 September 2001 have created a new paradigm for homeland security in Illinois that is critically dependent upon the planning, preparation and actions taken locally. This is a paradigm that is reminiscent of the struggle undertaken in America more than two centuries ago. Now, as then, the actions of each person and community are central to successful Homeland Security in the 21st Century.



# DECISION-MAKING IN TIMES OF UNCERTAIN CRISES: CONSUMERS' RISK ATTITUDES AND RISK PERCEPTIONS

**Joost M.E. Pennings**

## ABSTRACT

A conceptual framework for policy makers to analyze consumer behavior in times of crises is presented. The framework provides policy makers and the agricultural industry with a tool to structure the discussion on how to communicate crises to consumers and serves as a basis for concrete marketing policy. The merits of this conceptualization are illustrated in two field studies that examine the reactions of German, Dutch, and American consumers to the bovine spongiform encephalopathy (Mad Cow disease) crisis. The findings of this research can be found in the following resources: Pennings, J.M.E (2002) Should the Government Warn Us: Decision-Making in Times of Uncertain Crises, *Working paper, University of Illinois at Urbana-Champaign, Department of Agricultural and Consumer Economics;* and Pennings, J.M.E, B. Wansink, and M.T.G. Meulenberg (2002) A Note on Modeling Consumer Reactions to a Crisis: The Case of the Madcow Disease, *International Journal of Research in Marketing* 19: 91–100.

## INTRODUCTION

Companies and governments are increasingly exposed to potential crises every day and, as a result, being a policy maker seems to be getting harder and harder. The Firestone tire case showed that policy makers need to understand why and how consumers react to crises such as safety issues. The inability to respond swiftly and effectively can devastate an industry, even across a continent. During the Mad Cow crisis, for example, German beef consumption dropped 60% during the last quarter of 2000, bringing its beef industry to bankruptcy. Crises, of which the content and the likelihood of actually being exposed to that content are uncertain, are particularly hard to manage for policy makers. This article aims to offer policy makers a framework for managing crises.

To formulate an effective policy, policy makers need to understand consumer reactions in times of crisis. Two dimensions play a crucial part in consumer reactions to crises such as food contamination: the content of the crisis and the likelihood of actual exposure to that content. The first dimension refers to the impact of an event. The second dimension reflects the likelihood that the content of the risk actually becomes manifest. The likelihood that the risk content occurs can be known or unknown, the latter case often being referred to as "uncertainty" (Hirshleifer and Riley 1992, Knight 1993).[1]

These two dimensions, risk content and the likelihood of exposure, are directly related to the two fundamental drivers of decision behavior under uncertainty: risk attitude and risk perception. Risk attitude and risk perception are two different concepts. Risk attitude deals with the consumer's interpretation of content of the risk and how much he or she dislikes the risk, whereas risk perception deals with the consumer's interpretation of the chance to be exposed to the content of the risk (Pennings and Smidts 2000). Risk attitude reflects a consumer's general predisposition to a particular risk in a

[1] Hirshleifer and Riley (1992), disregard Knight's distinction between risk and uncertainty, but make a distinction between hard and soft probability. Other researchers use the term *ambiguity* when referring to the situation when probabilities of the event are not known.

consistent way, and hence is formed by the content of that risk (i.e., the first dimension). Risk perception reflects the consumer's own interpretation of the likelihood of being exposed to the content of the risk and may therefore be defined as a consumer's assessment of the uncertainty of the risk content inherent in a particular situation. Hence, it is driven by the likelihood of exposure to the risk content (i.e., the second dimension).

Risk attitudes range from extremely risk-averse (i.e., refusing any risk under any condition) to extremely risk-seeking (i.e., always preferring a risk-carrying outcome), whereas risk perceptions range from high to no risk perception at all. It is the interaction between both concepts that drives decision behavior, because it reflects the consumer's predisposition to deal with the risks inherent in the risk content and the risks that their reactions to this risk content generate (Pratt 1964, Arrow 1971, Pennings and Wansink 2003). For example, a consumer might be highly risk-averse towards food contamination. Yet, whether he or she will actually take precautions depends on risk perception: if this consumer estimates the likelihood of food contamination at zero, he or she will not take any precautions. Only when the consumer is both risk-averse and perceives risk will he or she show preventive behavior (towards food contamination).

Thus, the entire behavioral outcome space, which contains all possible behaviors of consumers, is driven by the interaction between the consumers' risk attitudes and risk perceptions and can be written as follows:

$$BS = \int_{i=1}^{I} B_i = \int_{i=1}^{I} RA_i * RP_i \qquad (1)$$

where $BS$ is the behavioral outcome space, reflecting the set of consumers' behaviors; $B_i$ is the behavioral outcome of consumer $i$; $RA_i$ is the risk attitude of consumer $i$, and $RP_i$ is the risk perception of consumer $i$.

## CONCEPTUAL FRAMEWORK

This conceptualization has often been used successfully in economic literature to describe and explain behavior (Holthausen 1979). In that context, however, the risk content is often well-understood (e.g., price fluctuations), whereas the likelihood of exposure to that risk content can often be formulated as concrete probabilities: commodity prices, for example, follow a random walk, as prices can go up or down with equal probability (Cargill and Rausser 1975).

However, risk is not exactly known or estimable in the types of crises that policy makers face increasingly. Consumers, in other words, are unable to form a risk attitude, because they do not know the exact content of the risk. They cannot form a risk perception either, because they are incapable of judging the likelihood (i.e., probability) of exposure to the risk content. In terms of eq. 1, the risk attitude and risk perception of consumer $i$ have become uncertain variables, resulting in a flatter distribution function (i.e., larger variances) of risk attitudes and risk perceptions than would have been the case had the risk content and the probability of exposure been known.

Because risk attitudes and risk perceptions span the entire behavioral outcome space, this space will increase in such a situation, theoretically even to infinity, and increase the chances of what might be called extreme and, as such, nondesired behavior within the behavioral outcome space. Extreme or nondesired behavior may become manifest as individual behavior, such as reluctance to by the

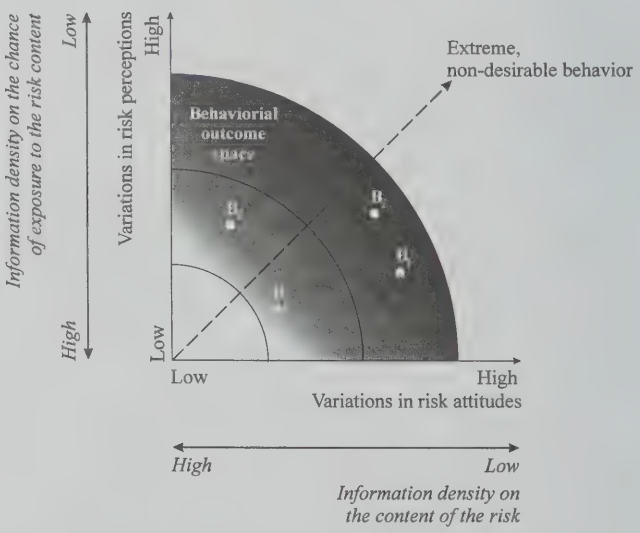



**Figure 1 ■ Behavioral Outcome Space in Times of Uncertain Crises.**

Where $B_i$ is the behavioral outcome of consumer $i$. The behavioral outcome space is the set of all individual behavioral outcomes. Figure 1 shows that the behavioral outcome space is spanned by the variations in risk attitudes and risk perceptions. These variations increase as the information density on the content of the risk and on the chance of exposure to the risk content decrease, thereby expanding the behavioral outcome space.

product, or as collective behavior, causing economic phenomena such as a stock market crash.

Figure 1 visualizes the relationships between the behavioral outcome space, on the one hand, and the variation of risk attitudes and risk perceptions and their drivers (information density on the content of the risk and on the chance that the risk content occurs, respectively), on the other hand. Figure 1 shows that the behavioral outcome space is the sum of the behaviors of all individual consumers (written in the figure as $B_i$).

It is of eminent importance to policy makers to keep the behavioral outcome space as small as possible to minimize the chances of extreme and nondesirable behavior. Minimizing the behavioral outcome space reduces the uncertainty about consumer reactions, making it easier for policy makers to develop a policy and to communicate it to the people. Moreover, it is easier for policy makers to respond to consumer reactions when they do not diverge too much.

## HOW POLICY MAKERS CAN MANAGE CRISES

Policy makers can minimize the behavioral outcome space by clarifying the risk content and by concretely defining the likelihood of exposure as much as possible (i.e., probabilities or degrees of risk: high, medium, or low) (Anand 2002). Doing so will stimulate the formation of risk attitudes and risk perceptions among consumers, leading to a smaller behavioral outcome space.

## THE MAD COW DISEASE CASE

The bovine spongiform encephalopathy (BSE) crisis, often referred to as the Mad Cow disease, fanned out across Europe, causing consumer panic and disrupting meat markets. For example, Figure 2 shows a dramatic decrease in beef consumption when the first BSE case was detected in Germany on November 26, 2000. Despite the fact that during this time of the year (holiday season) the German beef consumption is the highest of the year, consumption decreased dramatically (compare the period October–January in 1999 with the same period in 2000). Even outside or Europe the ramifications of the European BSE crisis

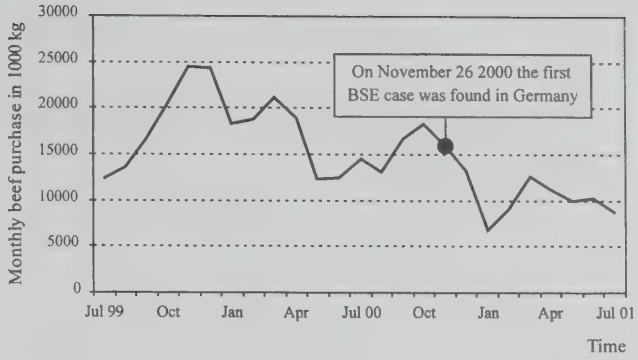



**Figure 2 ■ German monthly domestic beef purchase for the period July 1999–July 2001 (Source: GfK).**

put intense pressure on foreign government agencies, industries, and policy makers (Wadman 2001).

One of the biggest concerns with BSE is that contaminated beef can cause the Creutzfeldt-Jacob Disease (CJD) in humans (Abbott 2001). Yet, because the chance of receiving CJD by eating beef is extremely small (World Health Organization reports only 87 cases of CJD during the period October 1996–December 2000), it is puzzling that consumers react the way they do (Aldhous 2000).

What explains the different consumer reactions to such a crisis, and what solution is most effective? Our framework is useful in determining whether and to what extent risk perception and risk attitude contribute to the consumers' reactions. Predicting how consumers will react to a market crisis has important managerial implications. If beef consumption is primarily driven by risk perceptions (the likelihood of contracting CJD), the solution of the BSE crisis lies in effectively educating consumers about the level of risk involved. If, however, the consumers' response to the BSE crisis is primarily driven by risk attitude (risk aversion), the beef industry has fewer and costlier options, namely, to test each cow for BSE and to slaughter those which test positive. In a third case, it may be that consumers' responses are driven by the interaction between risk attitude and risk perception. In this case, some combination of both solutions will be needed to deal with the crisis. To better understand the impact of BSE on consumer behavior, two key questions need to be answered: 1) Why do consumer reactions to BSE vary across countries? 2) How do changes in levels of risk affect beef consumption?

Our objective was to examine these questions in a natural experiment that would generate behavioral

**Table 1 ■ Cross-country differences in knowledge about CJD and beef consumption.**

| | United States | Germany | Netherlands |
|---|---|---|---|
| **What do you think contracting Creutzfeldt-Jacob Disease (CJD) from eating beef will do to you?**[1] | | | |
| I would die; there is no treatment | 24.1% | 58.7% | 58.1% |
| I might die, but there is treatment and a chance of surviving | 31.5% | 19.5% | 17.8% |
| I would get very ill, and the illness would be chronic | 19.4% | 9.7% | 15.3% |
| I would get ill, and will recover after some time | 19.4% | 4.0% | 4.5% |
| I would feel ill, but would recover fast | 5.6% | 8.1% | 4.3% |
| **What do you think is your chance of getting CJD from eating beef?** (1, small; 9, large)[2] | 2.92 | 3.42 | 2.77 |
| **Are you concerned about eating beef?** (1, not concerned; 9, very concerned)[2] | 3.74 | 6.27 | 3.80 |
| **Do you trust the information that your government provides?** (1, do not trust; 9, fully trust)[2] | 5.93 | 3.42 | 5.00 |
| **Have you reduced your beef consumption because of the BSE crisis?**[1] | 17.8% | 58.1% | 22.9% |
| **By what proportion have you reduced your beef consumption?**[1] | 54.6% | 77.7% | 56.4% |
| **Have you switched to other meat products and fish products?**[1] | 17.8% | 49.0% | 19.7% |

[1] All cross-country differences were significant. Chi-square tests on the independence between countries resulted in $p$ values less than 0.02.

[2] The hypothesis that the means of these variables of the three countries is equal was rejected at the 5% level using an ANOVA analysis.

insights that might illustrate the importance of different policy measures. To accomplish this, German, Dutch, and American consumers were selected because they represented a wide range of responses to the BSE crisis.[2] In all, 298 German, 223 Dutch, and 228 American consumers were intercepted while shopping in their home countries and were interviewed in the last week of January and the first week of February 2001.[3,4]

The focus of the first part of the study was on BSE risk perceptions, risk attitudes, and beef consumption. We used a scaling procedure to measure risk attitude and risk perception, thereby recognizing that our empirical study did not exactly follow the Pratt and Arrow framework outlined in the conceptual framework.[5] Based on the work of Childers (1986), MacCrimmon and Wehrung (1986, 1990), Pennings and Smidts (2000), and Pennings and Garcia (2001), we developed scales that were consistent with our definition of risk perception and risk attitude and that were as closely as possible related to the Pratt and Arrow framework. In two prestudies we tested several different scales on convergent validity and nomological validity.

## Why do consumer reactions to BSE vary across countries?

The dramatic differences in consumers' reactions to the BSE crisis are shown in Table 1. The differences between the United States and the European countries are not surprising because BSE has never been a problem in the United States. Most illustrative here, however, are the large differences between neighbors. Both Germany and The Netherlands have a similar experience with the severity of the disease. Yet, as shown in Table 1, most of the Dutch perceptions resemble American rather than German perceptions. In general, the Dutch and Americans are less concerned about eating beef than the Germans, and they estimate their chance of contracting CJD relatively lower.

One explanation for these different levels of concern may be because American and Dutch consumers are

[2] In The Netherlands and Germany several cases of mad-cow disease have been reported. Since 1991, the United States has taken measures to protect itself by banning imports from BSE-contaminated countries and animal feeds.

[3] Because the same content of the questionnaire was being used across countries, the precise wording was modified through backward-translation procedures.

[4] The average age of the consumers ranged from 42 years in The Netherlands to 45 years in Germany, and the percentage of women in the three samples ranged from 51% in Germany to 60% in the United States.

[5] Some researchers have measured the Pratt and Arrow coefficient of absolute risk aversion by using the certainty equivalence technique (e.g., the lottery technique) and measured risk perception by assessing the probability function of respondents using the interval technique [see for an application Smidts (1997), and for a detailed description of these techniques Keeney and Raiffa (1976), Hershey and Schoemaker (1985), and Farquhar (1984)]. A drawback of these measurements is that it takes a lot of effort and time from the respondents, because they can only be obtained by time-intensive experiments. Furthermore, these elicitation techniques are extremely costly to conduct on a large scale.

more trusting of the information from their governments than are the Germans. As noted in Table 1, consumer confidence in government-issued information is significantly related to consumer concern in all three countries, and although the Germans have relatively low trust in government information (3.42), both the Dutch and the Americans are highly trustful of their food regulatory agencies (5.00 and 5.93). Indeed, in the United States, 83% trust the Food and Drug Administration, making it the most trusted government organization after the Supreme Court (Wansink and Kim 2001). Without trust in the information about BSE, fear and overestimates of risk may dramatically decrease beef consumption.

**Table 2 ■ Explaining consumer beef reduction with risk attitude, risk perception, and their interaction.**

| | Risk Attitude (RA) | Risk Perception (RP) | RAxRP |
|---|---|---|---|
| Did you reduce your beef consumption because of the BSE crisis (0, no; 1, yes)? Results of logistic regression. | | | |
| | $\gamma_1$ | $\gamma_2$ | $\gamma_3$ |
| **United States** | **-0.920*** | 0.189 | **0.220*** |
| Nagelkerke's $R^2$ = 0.517 | (0.020) | (0.402) | (0.002) |
| Correctly classified choices = 84.9 % | | | |
| **Germany** | **-0.549*** | **0.688*** | 0.440 |
| Nagelkerke's $R^2$ = 0.663 | (0.021) | (0.000) | (0.315) |
| Correctly classified choices = 86.6% | | | |
| **The Netherlands** | -0.137 | **0.726*** | -0.033 |
| Nagelkerke's $R^2$ = 0.442 | (0.687) | (0.000) | (0.707) |
| Correctly classified choices = 85.4% | | | |

Note: An asterisk indicates that each parameter significant improves the fit compared with the null model, which includes only an intercept, at the 5% level. Nagelkerke's $R^2$ is similar to the $R^2$ in linear regression and measures the proportion of variance of the dependent variable (reduction of beef consumption) about its mean that is explained by the independent variables (risk attitude, risk perception, and their interaction).

How do these combined variations in risk perceptions and risk attitudes influence consumer decisions about whether to reduce beef consumption? Logistic regressions indicated that there were significant variations across countries (Table 2). Although risk perceptions drive the Dutch decision to decrease beef consumption ($\gamma_1$= 0.726; $p < 0.01$), risk attitudes drive the American decision ($\gamma_2$= –0.920; $p < 0.02$). German behavior is determined both by risk attitudes ($\gamma_1$= 0.688; $p < 0.00$) and risk perceptions ($\gamma_2$= –0.549; $p < 0.02$).

### How would accurate information change behavior in a crisis situation?

If consumers in these three countries had equally accurate (and trusted) information, and if they had an equal risk of contracting CJD, would these differences still exist? That is, are the differences we see between countries circumstantial, or do they represent different ways in which consumers use risk information to modify their behavior? To some extent, this might vary across the level of risk that's involved.

To answer this question, all 749 consumers were presented with the four following scenarios: "Imagine that science had shown with absolute certainty that the chances of getting CJD from eating beef are . . ." 1 in **10 million** (scenario 1), 1 in **1 million** (scenario 2), 1 in **100,000** (scenario 3), 1 in **10,000** (scenario 4). Then, the consumers stated whether they would reduce their beef consumption in this scenario, and by how much they would reduce it.

Table 3 shows that the difference in the percentage of consumers reducing their beef consumption between consecutive scenarios is largest between scenario 2 and scenario 3, and the proportional decrease in beef consumption (per capita) is largest between scenario 3 and scenario 4. This result suggests that when a country faces a mild chance of BSE contamination (e.g., less than 1 chance in a million), national beef consumption will decrease because a larger number of consumers will reduce their beef consumption. However, when facing a serious chance of contamination, such as scenario 4, a radical decrease per capita consumption is the main cause of the decrease of consumption.[6]

Previously, we examined how beef consumption was influenced in the present situation where consumers have inaccurate information about the probabilities of contracting CJD. How is consumption changed

[6] The notion that risk attitude is context specific (March and Shapira 1992), i.e., the attitude toward risk (beyond a general propensity) depends upon the level of risk, is confirmed in this study. The risk attitude score decreased (i.e., consumers become more risk averse) monotonically when going from scenario 1 to scenario 4 for all consumers across all countries.

Table 3 ■ How changes in the probability of contracting CJD will change beef consumption.[1]

| Suppose that science had shown with absolute certainty that the chances of getting CJD by eating beef are . . . | Percentage of Consumers That Decide to Reduce Their Beef Consumption | | | Proportion by Which Consumers Diminish Their Beef Consumption | | |
|---|---|---|---|---|---|---|
| | United States | Germany | Netherlands | United States | Germany | Netherlands |
| **Scenario 1**: 1 in **10 million** per year | 34.3% | 40.9% | 35.0% | 41.3% | 73.2% | 66.9% |
| **Scenario 2**: 1 in **1 million** per year | 47.3% | 49.8% | 48.9% | 48.8% | 77.7% | 73.4% |
| **Scenario 3**: 1 in **100,000** per year | 68.5% | 66.7% | 75.8% | 57.6% | 80.6% | 78.0% |
| **Scenario 4**: 1 in **10,000** per year | 73.5% | 75.2% | 86.5% | 69.7% | 91.1% | 89.1% |

[1] The hypothesis that the means of these variables of the three countries is equal was rejected at the 5% level using an ANOVA analysis.

when they have accurate information? The logistic regression results in Table 4 shows risk perception influences all three countries for all scenarios either directly or indirectly through its interaction with risk attitude. Even when accurate information is available, risk attitude remains an important driver of beef consumption in the United States and Germany, and becomes important in The Netherlands in high-risk scenarios.

In general, it can be observed from Table 4 that the influence of risk attitude on beef consumption increases with an increasing chance of contamination (scenario 1–4), except for Germany. The latter deviating result may be caused by the extreme risk aversiveness of Germans, leading to homogeneity in the impact of risk attitudes on beef consumption. On the other hand, the impact of risk perception on beef consumption does not systematically increase with more risky situations (scenario 1–4). In the United States, there is little or no difference across scenarios. In The Netherlands, no systematic increase of the influence of risk perception can be observed from scenario 1 to scenario 4, whereas for German consumers an increase can be found in scenario 4.

### What is the answer to the BSE crisis?

Our research demonstrates that the way policy makers respond to the BSE crisis should take into account whether a country's beef consumption is influenced more by risk perceptions or by risk attitudes. The relative influence of risk perception and risk attitude on beef consumption depends, among others, on the accuracy of knowing the probability of getting CJD from eating beef.

If the probability of contracting CJD *is not* accurately known, which is the current situation, this analysis suggests different policy implications for different types of countries. In countries such as the United States, tough measures are required to prevent a BSE crisis because risk attitudes drive consumption and little can be done to change consumers' risk attitudes. Thus, testing and slaughtering all suspected cows. In countries such as Germany, both risk perceptions and risk attitudes drive consumer behavior, suggesting not only the need for tough measures but also for extensive and responsible dissemination of accurate information by government, industry, and media. In contrast to the United States and Germany, Dutch consumer behavior is driven mainly by risk perceptions. In this case, honest and consistent communication by both the government and the beef industry is more effective than a mass slaughtering of cows.

If the probability of contracting CJD is accurately known (or becomes more accurate), risk perception becomes a more important driver of beef consumption than risk attitude in low and mildly risky situations (such as scenarios 1 and 2) in the United States and The Netherlands. In low-risk situations, messages from the government, the beef industry, and the media will have a notable impact on helping consumers respond to the BSE crisis (Tversky and Kahneman 1981, Slovic 1987). In contrast, with high-

**Table 4 ■ How different risk levels influence beef consumption.**

| | Risk Attitude (RA) | Risk Perception (RP) | RAxRP |
|---|---|---|---|
| | $\beta_1$ | $\beta_2$ | $\beta_3$ |
| **United States** | | | |
| Scenario 1 ($R^2$ = 0.47, cc = 81.3%) | **-0.298*** | **0.525*** | 0.010 |
| Scenario 2 ($R^2$ = 0.49, cc = 76.4%) | **-0.309*** | **0.470*** | 0.005 |
| Scenario 3 ($R^2$ = 0.52, cc = 84.2%) | **-0.752*** | **0.544*** | 0.047 |
| Scenario 4 ($R^2$ = 0.51, cc = 82.8%) | **-1.128*** | **0.515*** | **0.090*** |
| **Germany** | | | |
| Scenario 1 ($R^2$ = 0.56, cc = 82.8%) | **-0.403*** | 0.218 | **0.045*** |
| Scenario 2 ($R^2$ = 0.65, cc = 84.5%) | **-0.473*** | **0.282*** | **0.071*** |
| Scenario 3 ($R^2$ = 0.64, cc = 88.1%) | **-0.543*** | 0.212 | **0.066*** |
| Scenario 4 ($R^2$ = 0.65, cc = 90.5%) | -0.332 | **0.456*** | 0.002 |
| **The Netherlands** | | | |
| Scenario 1 ($R^2$ = 0.56 cc = 83.0%) | 0.203 | **0.577*** | 0.040 |
| Scenario 2 ($R^2$ = 0.61, cc = 83.6%) | 0.285 | **0.744*** | 0.052 |
| Scenario 3 ($R^2$ = 0.66, cc = 91.4%) | **-0.477*** | 0.032 | **0.081*** |
| Scenario 4 ($R^2$ = 71.4, cc = 94.6%) | **-0.647*** | **0.590*** | 0.034 |

Scenarios 1 to 4 go from least risky to most risky. An asterisk indicates that each parameter $\beta$ significantly improves the fit compared with the null model, which includes only an intercept, at the 5% level. The reported cc is the correctly classified choices (e.g., the predictive validity).

risk situations (such as scenario 4) tough measures—recall or elimination—are also necessary. In the case of strongly risk aversive consumers, however, any level of risk is treated as a high-risk situation. As a result, tough measures and information are important, even in low and mildly risky situations. On the production side, an ounce of prevention is worth a pound of cure, but on the policy side, an ounce of information is worth even more.

## CONCLUSIONS

We argue that the behavior of consumers in a crisis can be better understood by decoupling risk response behavior into the separate components of risk perception and risk attitude. This conceptualization provides information about the tools that might be used to deal with a crisis. We find that behavior toward a risk-related crisis (such as food safety) is driven by different factors for different segments and that the relative influence of these variables depends on the accuracy of knowing the probability that the risky event occurs.

These findings have important managerial and public policy implications. If consumers' behavior is driven primarily by risk perceptions, the solution lies in combining consistent and effective communication with ongoing efforts to reduce the risk. If consumers' behavior is instead driven by risk attitudes, such as extreme risk aversion, in the end the only effective efforts will lie in eliminating the risk.

Our empirical application to the BSE crisis illustrates the strengths of the proposed framework. If consumers' reactions are mainly driven by risk perception, effective communication efforts can increase the consumers' knowledge about the probabilities of being exposed to the risk (e.g., getting CJD) may be sufficient. If, however the consumer response to the crisis is mainly driven by risk attitude, the marketer has fewer options. In fact then, ultimately, the only tool available is to eliminate the risk (e.g., slaughter all cows that might have BSE, or check every single cow for BSE).

The three-country study showed significant differences in consumers' risk attitudes and risk perceptions and consequently consumers' reactions. Interestingly, our findings regarding risk attitudes are consistent with the landmark findings of Hofstede (1980) some 20 years ago. Understanding these cross-cultural differences is particularly critical for managers and public officials who need to predict how and why consumers in different countries respond to a crisis.

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## REFERENCES

Abbott, A. 2001. BSE fallout sends shock waves through Germany. Nature 409: 275.

Aldhous, P. 2000. Inquiry blames missed warnings for scale of Britain's BSE crisis. Nature 408: 3–5.

Anand, P. Decision-making When Science is Ambiguous. Science 259: 1839.

Arrow, K.J. 1970. Essays in the Theory of Risk Bearing. Chicago, IL: Markham Publishing Company.

Cargill, Th.F., and G.C. Rausser. 1975. Temporal price behavior in commodity futures markets. Journal of Finance 30: 1043–1053.

Childers, T.L. 1986. Assessment of the psychometric properties of an opinion leadership scale. Journal of Marketing Research 23: 184–188.

Farquhar, P. H. 1984. Utility assessment methods. Management Science 30: 1283–1300.

Hershey, J.C., and P. Schoemaker. 1985. Probability versus certainty equivalence methods in utility measurement: are they equivalent? Management Science 31: 1213–1231.

Hirshleifer, J., and J.G. Riley. 1992. The Analytics of Uncertainty and Information. Cambridge, MA: Cambridge University Press.

Hofstede, G., 1980. Culture's Consequences: International Differences in Work-Related Values. Beverly Hills/ London: Sage Publications.

Holthausen, D.M. 1979. Hedging and the competitive firm under price uncertainty. American Economic Review 69: 989–995.

Keeney, R.L., and H. Raiffa. 1976. Decisions with Multiple Objectives: Preferences and Value Tradeoffs. New York, NY: John Wiley & Sons, Inc.

Knight, F.H. 1933. Risk, Uncertainty and Profit. Boston, MA: Houghton Mifflin.

MacCrimmon, K.R., and D.A. Wehrung. 1986. Taking Risks: the Management of Uncertainties. New York, NY: The Free Press.

MacCrimmon, K.R., and D.A. Wehrung. 1990. Characteristics of risk-taking executives. Management Science 36: 422–435.

March, J.G., and Z. Shapira. 1992. Variable risk references and the focus of attention. Psychological Review 99: 172–183.

Pennings, J.M.E. 2002. Should the government warn us: decision-making in times of uncertain crises. Working paper, University of Illinois at Urbana-Champaign, Department of Agricultural and Consumer Economics.

Pennings, J.M.E., and P. Garcia. 2001. Measuring producers' risk preferences: a global risk attitude construct. American Journal of Agricultural Economics 83: 993–1009.

Pennings, J.M.E., and A. Smidts. 2000. Assessing the construct validity of risk attitude. Management Science 46: 1337–1348.

Pennings, J.M.E., B. Wansink, and M.T.G. Meulenberg. 2002. A note on modeling consumer reactions to a crisis: the case of the Mad Cow disease. International Journal of Research in Marketing 19: 91–100.

Pennings, J.M.E. and B. Wansink. 2003. Channel contract behavior: the role of risk attitude, risk perceptions, and channel members' market structures. Journal of Business (in preparation).

Pratt, J.W. 1964. Risk aversion in the small and in the large. Econometrica 32: 122–136.

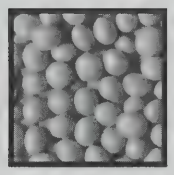
Slovic, P. 1987. Perception of risk. Science 236: 280–285.

Smidts, A. 1997. The relationship between risk attitude and strength of preference: a test of intrinsic risk attitude. Management Science 43: 357–370.

Tversky, A., and D. Kahneman 1981. The framing of decisions and the rationality of choice. Science 211: 453-458.

Wadman, M. 2001. Agencies face uphill battle to keep United States free of BSE. Nature 409: 441–442.

Wansink, B., and J. Kim. 2001. The marketing battle over genetically modified foods: Mistaken assumptions about consumer behavior. American Behavioral Scientist 44: 1405–1417.



# NATIONAL PLANT PEST AND DISEASE NETWORK: INCREASED VIGILANCE FOR AGRICULTURAL SECURITY

**K.F. Cardwell**

The primary goal of an agricultural biosecurity program is to prevent entry of a pathogen or pest into plants, animals, or the food supply. When preventive measures fail, it is imperative to have early detection, rapid and accurate assessment, and immediate response that prevents spread, controls the infection, and then begins the recovery phase.

In response to 9/11/01, a $20 million grant was released by the Secretary of Agriculture to Cooperative State Research, Education, and Extension Service (CSREES) to develop a network linking plant and animal disease diagnostics clinics across the country. CSREES is the branch of the Federal U.S. Department of Agriculture system that works directly and exclusively with state university and agricultural experiment stations. Thus, the objective is to build a network using the state systems to mobilize all stakeholders on the ground throughout the country to increase their awareness of the potential and vigilance for intentional introduction of pests and pathogens of agricultural importance. The purpose of the network is to

- Enhance biosecurity by rapid detection of diseases and pests introduced into the U.S. agricultural production system
- Form a strong, vigilant network to monitor and detect unusual animal disease and plant pest outbreaks at the multistate and pan regional level
- Enhance coordination between Federal USDA agencies
  - CSREES
  - Animal Plant Health Inspection Service (APHIS)
  - Agricultural Research Service (ARS)
- Develop detection and response pathways and standard operating procedures with partners with National Agricultural Pest Information System (NAPIS), State Departments of Agriculture, Regional Pest Management Centers, Land Grant Universities, and private laboratories.

Lead universities have been selected and designated to represent four (five) regions around the country. The animal sector has 13 sites around the country, and the plant sector six. From here on we will be talking only about the plant sector. There are five regions: Western, Great plains, North central, Southern and Northeastern. A 6th site, Purdue University, was selected to be the central repository for select data from all regions. A strategy of action to link the states within the regions and the regions across the country is in place, to be coordinated by the lead universities in each of the regions.

The work has to span from agricultural fields to response and remediation operating procedures (Figures 1–3).

## FIELD

We have a huge job of getting our first detectors to buy in on the program and to know what to do.

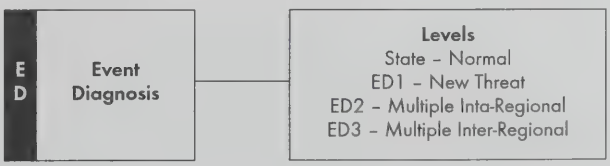



**Figure 1 ■ Event Diagnosis Levels.**

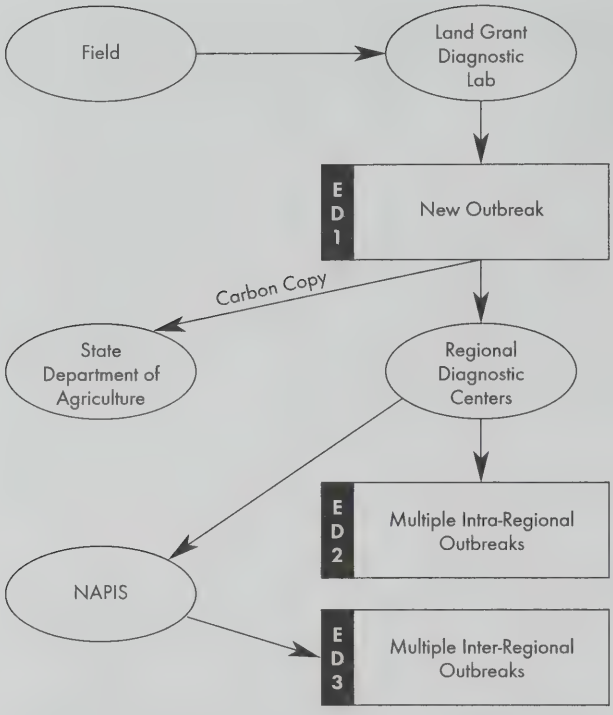



**Figure 2 ■ Sampling & Diagnostic Data Pathway.**

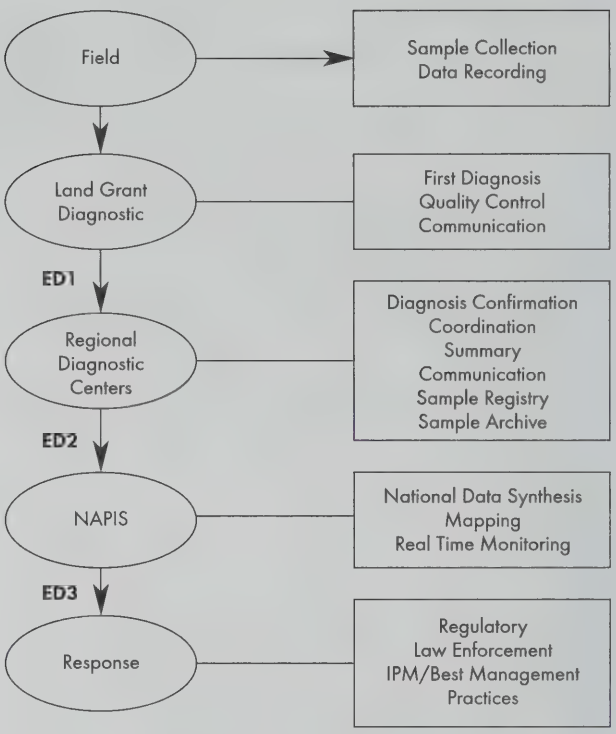



**Figure 3 ■ Action Pathway.**

There will be a very large development and training component for the crop pest managers, who include the following:

- Growers
- Natural resource managers
- Chemical, seed, and fertilizer industry representatives
- County extension agents
- University and state extension agents
- Certified crop consultants
- Master gardeners
- IPM specialists

To get stakeholder buy-in, people will have to understand that this goes beyond market competition. There is a patriotic duty involved here. Homeland security for agriculture has to be a grass roots endeavor, with every person in the field being a soldier. First reports of something new or suspicious may be made by growers themselves, and if the first report comes in a timely manner, we will have a much better chance of responding quickly and effectively.

## DIAGNOSTIC LABORATORIES

In addition to getting the first detectors organized and vigilant, we have a huge task of getting the regional diagnostic facilities organized and coordinated. Each region contains 8–12 states and territories. Every state has its own unique system for handling pest problems. In many (but not all) states the State University together with the USDA–ARS has plant diagnostic laboratories and research facilities. Diagnostic services are provided to general public and researchers, usually on a fee basis. Research and service collaboration is common, often in proximity, for state and federal partners. In many (but not all) states, there is a parallel system of State Department of Agriculture diagnostic laboratories, often partnered with the USDA–APHIS personnel. In these laboratories, diagnostic services are provided to general public and law enforcement officials. Often, there are parallel and cooperative statutory authority and law enforcement goals for these offices. Plant protection act, noxious weeds act, and other laws are sometimes "parallel" in states, meaning that the state law mirrors the federal law. There are some acts (like the nursery act) where state officials actually go out and enforce federal law.

It will be necessary to have good communications among all of the players in the different disciplinary settings and university, state, federal, and private laboratories within each state. The strategy is to "capture," i.e. collect, collate, and record, as much field-based disease and pest outbreak information as early as possible. The field and state diagnostic level is where the first awareness of a new problem might be detected, called herein event diagnosis I (ED I) (Figures 1 and 2). Once a comprehensive data capture at the state level is achieved, it needs to be brought to a regional level for confirmation, collation, proper encoding, and real-time monitoring (Figure 3). The regional level is where event diagnosis (ED II) might occur, where the regional laboratory and coordinating facility personnel notice that there are multiple-state outbreaks of a new or unusual nature (Figures 1 and 2). There are a number of inherent interstate barriers to overcome if we are to achieve a coordinated regional network. There are tremendous individual points of excellence and expertise, however, until now, there has been

- Mission limitation (states have not been mandated to share data)
- Lack of personnel (most states have cut diagnostic capabilities)
- No regional connection or coordination
- No single point of data management
- No national resources.

The first step will be to develop the regional networks within each of the five regions.

Then, the regional network data will flow into a national pest information repository (NAPIS). This will result in a monitoring system similar to the concept of the Centers for Disease Control (CDC), which monitors human disease outbreak across the country. The NAPIS system was already designed for APHIS Cooperative Agricultural Pest Surveys, which were designed to scout for and record incidence of new and emerging pests of quarantine significance. NAPIS is also a Web-based resource that provides maps of pest outbreak across the United States. It will now be further developed to capture all data on crop disease and pest outbreak. This is where monitoring might evoke an event diagnosis III (ED III) in which the data observation at a national level makes it apparent that there are multiple outbreaks of a new or suspicious nature in multiple regions (Figures 1 and 2).

## RESPONSE

Within each region, the lead University organizes multiple stake-holder meetings to build the regional network. At the same time, there is a national steering committee that looks to ensure that there is a seamless mesh between the regions and that data flows into the national information repository and Purdue University. In the event of detection of an intentional release of crop pest(s) or pathogen(s) there will be specific operating procedures for appropriate and rapid response. For a "non-event," i.e., standard or normal disease and pest incidence, the response would be the usual recommendation from the crop consultants or extension specialist. In the case of an "event," the detection of new or unusual outbreak, the response will depend on the nature of the diagnosis. When an outbreak occurs with a new exotic pest, i.e., soybean rust or brown citrus aphid, particularly anything on national registry lists, the response will be proscribed by APHIS and may be an attempt at containment. If the outbreak is detected only at the ED II or III level, where there are already multiple outbreaks in various states or regions, the response is more likely to be one of rapid deployment of best management practices, and emergency registrations of whatever may be needed for control. Some outbreaks could result from intentional modification and redeployment of a weaponized pest. If there is evidence that intentional foul play was behind such outbreaks, the response is also likely to include intervention and investigation by local and federal law enforcement agencies.

Information on diagnoses must flow into a response pathway. It will either be at the remediation level in the regional IPM centers (already existing network), via extension and back to the growers, or there will be a national (federal) response. The terms of reference for some of the different organizations that will make up this network are listed below.

## REGIONAL PLANT DIAGNOSTIC CENTERS

- Provide plant diagnostic leadership and coordination to state and university diagnostic laboratories
- Survey the diagnostic resources in the region
- Create an effective communication network between regional expertise

- Establish harmonized reporting protocols with the national diagnostic network participants
- Catalog pest and disease occurrence to be included in national database (NAPIS)

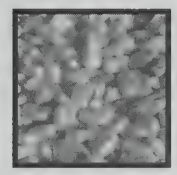
## NATIONAL AGRICULTURAL PEST INFORMATION SYSTEM (NAPIS)

- Provides plant pest survey data on a national scale
- Works in conjunction with the Cooperative Agricultural Pest Survey (CAPS)
- References all data to state and county
- Provides an information feed-back loop to APHIS and regional centers
- www.ceris.purdue.edu/napis

## REGIONAL PEST MANAGEMENT CENTERS

- The four centers are colocated with regional diagnostic centers at Michigan State, California (Davis), Florida, and Cornell
- Develop and maintain an information network of state diagnostic specialists and resources
- Create links between pest management extension, research, and production

There has been tremendous excitement about preparing this network. By 2003, we will engage in a "war games" scenario role play to see how responsive the system really is. You will be part of the simulation. Stand by for marching orders!



# THE REAL COST OF SPRAY CLAIMS

**Michael S. Smith**

Crop application claims may seem unavoidable given the frenzied pace involved, the potency of today's agrichemicals, the vagaries in weather and microclimates, the often difficult terrain and challenging neighboring exposures, and pressure from patrons and management. Yet some applicators have managed to eliminate almost all crop claims year after year while generating more income, reducing applicator turnover, and ridding themselves of problem accounts. Before I tell you how they accomplished this miracle, let's examine the fundamental economics of crop application claims.

The GROWMARK system of member cooperatives buys most of its insurance on a group basis, and most of the insurance premiums are based on system losses, with adjustments for particular cooperatives' own losses. With respect to crop application claims, each member is subject to deductibles of $5,000, plus 10% of the next $50,000, per claim—that is, a maximum per claim of $10,000. Under certain circumstances these deductibles can be cumulative. For example, if contaminated rinsate was added to a number of batches, the deductible would apply to each batch, and the member cooperative could suffer hundreds of thousands of dollars in deductible expense for one fundamental error. In the GROWMARK system group program, deductibles are capped at $50,000 for all losses arising out of one fundamental error.

In addition to the deductible expense, the amounts paid by the insurer excess of the deductibles affect system premiums for 5 yr because of the loss-sensitive rating model. Generally, insurers collect, over a sufficient period of time, approximately $2 for every dollar they pay in claims.

Assume a member cooperative operates at a 20% average gross margin. That's very generous, I know, but this illustration is meant to be conservative. Further assume a 3% net profit on that 20% gross margin. Most of GROWMARK's members consider themselves fortunate to earn 1%. To recoup a $10,000 deductible expense, the member cooperative would have to generate $333,000 of additional revenue. If one adds the increased insurance cost resulting from the $40,000 claim the insurer would have paid in this instance, the total revenue needed would be close to $3 million! Finding an additional $3 million of revenue is so difficult and having a $55,000 crop claim is so easy, doesn't it make sense to do everything in our power to eliminate crop claims?

Our cooperative members have their share of crop application claims. A few of the more interesting examples illustrate what can go wrong and the costly outcome of the mistakes.

Lorsban was sprayed on 38 acres of organic alfalfa, but it was in the wrong field. It takes 3 yr to recertify a crop as organic, so the farmer was paid for 3 yr of lost income. In addition, the alfalfa (no longer organic) was fed to organic cows, making the beef no longer organic, so we had to pay the rancher for that loss as well. The total reserve on this still open claim is $90,000.

Tank contamination caused stunted growth of beans and there were multiple claimants. The cooperative had to pay four deductibles of $5,000 to $10,000 each, and the insurer paid a total of $11,920. Additional revenue ($1.3 million) should just about cover the member's total loss.

We are not always wrong, but we almost always pay if something goes awry. We sprayed Fusion onto fields surrounding new catfish ponds. The catfish farmer even rode with our applicator as he applied the chemical. The next day all the catfish died. The label on Fusion says, "Toxic to Fish." That's all the jury needed to hear, and the farmer was awarded $106,000. The jury ignored our expert witnesses who testified that if we had sprayed the entire contents of our rigs into the ponds it would not have been toxic enough to kill the fish. The real problem was that the farmer had overstocked the ponds to try to recover his capital investment the first year of raising catfish, the ponds had turned over, and the fish died of suffocation.

We sprayed urea on corn without consulting the farmer, who wanted anhydrous ammonia applied. It didn't rain and the yield was reduced on 262 acres of corn. This claim was turned in after harvest and cost $35,000. When we have to settle claims after harvest, they are always more costly than when we can settle them right after the damage is done. One reason is because the farmer always asserts that the damaged field would have yielded the bumper crop of all time if it hadn't been for our negligence. Second, there are many less costly ways of settling claims than waiting for harvest to determine the loss. Sometimes, adjusters buy the farmer a crop on the futures market. Sometimes, we replant the crop for the farmer.

We sprayed Prowl on beans off label and the loss was $60,000, which the insurer refused to pay. It is against the law to spray off label in most jurisdictions, and most insurance companies exclude claims arising out of off-label applications. There used to be considerable flexibility in this area, but the current hard insurance market has taken most of it away.

One of the more interesting and unusual claims happened when we sprayed corn and beans with a herbicide in fields that were contiguous to nursery stock of fruit and nut trees. The nursery owner was also spraying something on the seedlings at that time. Apparently, both chemicals volatilized and came down as a mixed product that severely damaged the seedlings. The cooperative manager insists his people did nothing wrong, but the insurance company paid $600,000 for the loss and the member cooperative paid its $10,000 deductible.

A recent claim was a real wakeup call for us. We sprayed Roundup that drifted onto half an acre of corn and destroyed it. This particular corn was very special corn—the result of a lifetime of research and experiment on the part of a scientist in his seventies. He asserted that this would have been the best corn ever, the highest and finest oil content, the most sugar, absolute perfection in every measure. He demanded $3 million for his loss, including punitive damages. The insurance company adjuster considered this an outrageous demand for only half an acre of corn, and consulted with us on how to handle it. We asked our staff agronomist if he could recommend any firm to investigate the claim. He made the recommendation, and the firm concluded that to reproduce the half-acre crop would cost about $1 million. That suggested that the claim was not as outrageous as it first seemed. The last I heard, the insurer had offered the scientist $2,500 for the lost crop. I suspect he is so angry over the offer he is rounding up a team of attorneys to press his case against us.

Our studies of crop claims show that the leading causes are drift (33%), contamination (23%), overlap, streaking and skipping (17%), improper timing (13%), wrong field (7%), mechanical (6%), and calibration (1%). The most costly claims are caused by tank contamination (50%) and drift.

There has been considerable crop claim inflation in recent years for a variety of reasons:

1. More acres serviced by custom application.
2. More no-till, therefore, more applications.
3. More concentrated and effective herbicides.
4. Increased workloads and time pressure.
5. Reduced crop tolerance.
6. Farmers are more litigious than they used to be.

Our experience tells us that there are several key ingredients in preventing crop claims. First, increased awareness is critical. Our applicators need to be sure, for example, the chemical is right for the crop, they are in the right field, conditions are not off label, and the tank and equipment are not contaminated. Raising awareness has to be an ongoing and persistent goal, receiving almost daily attention.

Applicators and mixers need to take pride in doing the job right. In three decades of studying losses, I have rarely found one that was not caused by human error. Thus, 999 of 1,000 claims are preventable.

Use cleaner, not just water, to clean tanks and equipment.

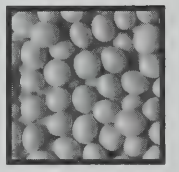
Avoid off-label applications in spite of time, and patron and supervisor pressure.

Avoid using volatile herbicides near sensitive crops such as specialty crops, orchards, nurseries, and especially vineyards. Vineyards cost a small fortune to establish, they don't produce a crop fit to make wine with for several years, and they are highly susceptible to herbicide damage. Every facility should have a map of its territory showing all the sensitive crops.

One of our members decided several years ago that crop claims were intolerably expensive, set out to eliminate them, and succeeded. I spent a day with the member ascertaining what led to the success. This was the formula:

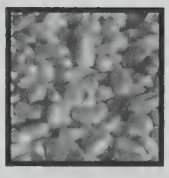
1. They gradually replaced all their equipment and used only stainless steel tanks.
2. They added internal cleaning mechanisms so they could clean the equipment in the field.
3. They mixed in the field, not at the plant, keeping the application equipment in the fields rather than on the road. The applicator planned his or her routes for the most efficient use of the equipment. Wherever possible, equipment was dedicated to a crop, reducing the need for cleaning.
4. They empowered their applicators. This, the manager told me, was the key ingredient. The applicator decides what to spray, when, and where, and no one, not even the manager, can override his or her decision.
5. They have a bonus system that rewards profitable application and punishes crop claims. If a potential claim is reported to management as soon as the applicator is aware of it then the penalty to the bonus is not as severe as if it is not reported. Management addresses any potential claim instantly and tries to take care of it before it becomes a claim.
6. The member fired its problem accounts. Some patrons repeatedly have problems, or they have neighbors who repeatedly cause claims. The member stopped servicing such patrons.
7. They stopped doing rescues. Almost every time we try to rescue a crop that is failing we end up getting sued when it doesn't work.

What were the results of these actions? The member now runs half the spray units it used to run. It sprays 95% of the acres it used to spray, in spite of firing a number of problem accounts. Its profits are up dramatically. They rarely have crop claims. There is no turnover in applicators. Indeed, the applicator position has become the most sought after in the company. They reduced their overhead. I don't know about you, but if I were a cooperative manager, I would jump on this example and instantly incorporate all its features for my own operations.



# DECIDING YOUR FUTURE

**Loren Bode**



# DRIFT REDUCTION STRATEGIES

**Mark F. Mohr**

One of the greatest concerns during a pesticide application is the possibility that a portion of the spray may blow into neighboring areas and cause damage. This is pesticide drift. Two strategies to reduce the possibility of that happening are to have knowledgeable applicators and to be a flexible manager. In the field, applicators should know the costs and causes of pesticide drift so that they will want and be able to avoid applications where drift is likely. This also means that managers need to be flexible about when and where applications are made, and must use innovative decision-making tools.

## THE COST AND CAUSES OF DRIFT

An applicator that understands the costs of drift will appreciate the need to avoid drift. These costs are high and climbing higher, whether they are insurance premiums, lost production, or environmental damage. There are many more, but these are a starting place to talk to fellow applicators about the problems associated with drift, and how each one can jeopardize the stability of the company, job security, and the future of crop protection at large.

Drift costs money. An annual cost of drift is seen in insurance bills that keep creeping (or leaping) higher. This is true even for companies without recent claims or settlements. In fact, the rising cost of insurance is a major drain on profit margins that are already thin. Even businesses that act responsibly suffer. Some costs may never be seen by the applicator, such as lost production. Even when drift damage goes unnoticed or unreported, lost production costs money. It may be a few hundred dollars of a conventional agricultural crop or it may be thousands of dollars of a specialty crop, landscaping, or livestock. An irresponsible application can cost you, your neighbors, and your customers money. In recent years Illinois has seen expanding production of specialty crops and increased niche marketing. Even if drift doesn't reduce yields, off-label pesticide residues may make the crop unsaleable and worthless. Another potential cost is environmental damage and the subsequent cleanup. An applicator should also be an "environmentalist" or a "conservationist" and have the goal of controlling only the pest, while impacting anything else as little possible. Drift contaminates air, land, and water. Contaminated air and water are mobile, and can further spread off-target pesticides—into protected habitat or drinking water for example. Animal or human illnesses from drifted pesticides are unacceptable under any circumstance. Instances such as these have turned many citizens against pesticides. Drift damages your personal and business reputation in your community as well as your profession's reputation in society. If drift is a persistent problem, citizens and governments will not tolerate pesticides and will demand alternatives and more regulations. In the long term, producers and applicators will loose important tools for controlling pests and will labor under burdensome regulations.

When an applicator knows drift is bad, how is it avoided? Applicators should know how droplets get blown off target, and what sensitive areas surround each application area. Training an applicator in these two topics is as important as knowing how to start and drive the sprayer, and should continue through-

out the applicator's career. It could be at University of Illinois Extension events, company training, field days, or just reading articles on pesticide drift. In fact, a combination of each of these is likely to be effective.

Other sessions at this year's conference will address the nuts-and-bolts of pesticide drift in detail, but it is important to know that drift is a matter of three components: the spray solution, the weather, and the spray equipment. Each of these will affect the potential for particle drift, vapor drift, or both. Applicators who understand the causes of drift will be better judges at knowing when an application should be stopped or when to move on to a different location.

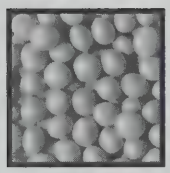
The other piece of information is to know is what surroundings are especially sensitive to drift. This is particularly important for chemicals that have vapor drift concerns. No matter what is in the spray tank, spraying upwind of a sensitive area is particularly risky. When the wind speed or direction places neighboring areas in the path of likely pesticide drift, an applicator should recognize the potential problem. The solution may be to stop the application, mark where the application ended, and go on to the next field until the wind is more suitable.

## FLEXIBLE APPLICATION MANAGEMENT

The capstone of a successful drift control strategy is flexibility. It means having the right mindset and technological solutions. It also means watching for new technologies that will reduce the possibility of drift. For years the advice has been to avoid getting in a situation where you think an application must be made "right now." Making applications when conditions favor drift invites disaster, but stopping in mid application used to result in difficult record keeping. However, new tools can help a manager keep track of applications in order to avoid making high-risk applications.

Help applicators identify sensitive areas by marking sensitive areas on field maps. Geographic Positioning System (GPS) equipped sprayers and scouting tools make mapping easier now than ever before. Fields next to sensitive areas can be sprayed when wind direction is blowing away from those areas. Another technology-based management tool is an "as applied" map. Many controllers are able to map areas as they are sprayed, which means if an application is halted midfield, it can be resumed later at the exact location it stopped. This could also be done as simply as marking the last pass and noting which direction to start spraying again when the wind is more favorable. What if you could keep a list, or database, of fields that are suitable to spray for different wind conditions? For a given tank mix (if it is the same from field to field) if the wind is not favorable to finish one field next to a sensitive area, go on to the next field and finish when the wind has changed. These are just a few of the management technologies that show promise for helping reduce complaints of pesticide drift.

Pesticide drift is a complicated problem, and the answer is not simple. One place to start is to have knowledgeable applicators and flexible strategies to help keep drift under control. The future depends on it.



# SOYBEAN RUST: PAST, PRESENT, AND FUTURE

**Glen Hartman**

## INTRODUCTION

Soybean rust is a major disease of soybean and one of the most important foliar diseases worldwide (Hartman et al. 1999). Significant yield losses have been reported in nearly all the major soybean-producing countries throughout the world with the exception of those in North America. Even before it was found in Hawaii in 1994, *Time* magazine in an October 13, 1993. issue had an article on the "*Attack of the Rust Fungus*," indicating that soybean rust was established in the United States, causing billions of dollars in damage. Although the pathogen has not been found in the continental United States, its occurrence in Hawaii in 1994 (Killgore 1995), Zimbabwe in 1998, South Africa in 2001 (Levy et al. 2002), Paraguay in 2001, and Argentina and Brazil in 2002 (personal observation and communication) has renewed interest in this disease in the United States. It was predicted that yield losses of greater than 10% may occur in nearly all of the U.S. soybean growing areas, with greater losses in the Mississippi delta and southeastern coastal areas (Yang 1995). Yield loss estimates in the Midwest are at this time best guests, although it has the potential to have a major impact on yield because all commercial cultivars are susceptible (Miles and Hartman, unpublished data), and the environmental conditions for infection and spread are conducive under normal growing conditions. There are other pieces to the puzzle that at present are not known, including whether the pathogen can become established from year to year. In other words, it may not be able to survive from one growing season to the next in the Midwest, but it may be able to survive further south in the coastal regions, Mexico, or Central America and then be blown as airborne spores from those regions to the north.

### Importance

Yield losses of up to 80% have been reported from experimental trials in many countries throughout Australasia (Hartman 1995). Heavily infected plants have fewer pods and lighter seeds. Marketable yields are even less because of poor seed quality. Because of the devastation to soybean yields, the U.S. Department of Agriculture began a research program on soybean rust at the containment facility at Fort Detrick, Frederick, MD, in 1971. A summary of this research has been published (Bonde and Peterson 1995). The pioneering research associated with this laboratory was unique because there are only a few locations in the world where comparative studies among fungal isolates throughout the world can be made without cross-contamination. Research at the containment facility determined the general susceptibility of the U.S. soybean crop and found that races existed among the cultures. Studies also were conducted to compare the cultures to determine the effects of temperature, dew period duration, and other environmental factors on spore germination, penetration, establishment of infection, and sporulation. This early research at Fort Detrick helped establish baseline information needed to better understand this disease and its pathogen. Today, the personnel at Fort Detrick remain active in rust research and serve as the focal point for several rust projects that include evaluations for new sources of resistance.

### Symptoms and Signs

The most common symptoms of rust are tan to dark brown or reddish brown polygonal lesions 2 to 3 mm in diameter with one to many raised round uredia with an apical opening (Figure 1). The disease

**Figure 1 ■ Rust lesions caused by *Phakopsora pachyrhizi* on soybean leaves (right) showing individual sporulating pustules (left).**

develops first as small, water-soaked lesions, which gradually increase in size, turning from gray to tan or brown. Lesions can occur on petioles, pods, and stems, but are most abundant on leaves, particularly on the under surface. The number of uredia per lesion increases as lesions age and produce urediniospores, 18–34 × 15–25 µm, that are wind blown (figure 2). Telia form subepidermally among uredia and are dark brown to black at maturity. They are crustose, irregular to round, sparse to aggregated and approximately 50 to 150 µm in diameter.

### Literature and Workshops

There are several comprehensive publications that have updated the current research at the time they were published. A brief chronological listing follows of some of these important events. One of the first workshops was held in Mayaguez, Puerto Rico, in 1976 (Vakili 1978). The focus of this workshop included aspects of the occurrence of rust in Puerto Rico and comparisons between the two different types known as the "old" world and "new" world rusts. Another workshop on rust was sponsored by the International Soybean Program (INTSOY) of the University of Illinois Champaign Urbana, was held in Manila, The Philippines, in 1977 (Ford and Sinclair 1977). This workshop stressed the problems and research needs in Australia and Asia. The potential threat to U.S. soybean also was discussed. The delegates at these workshops concluded that if either of the casual rust fungi were introduced and become established in the U.S. soybean production areas, the result could reduce soybean yields particularly in the southeastern United States. Another result of international collaboration was the start of the *Soybean RustNewsletter* that was first published by the International Working Group on Soybean Rust in 1977 with the last issue (Vol. 9) published in 1989. One of the first summaries in book form was produced by Bromfield . A bibliography of soybean rust was published by the Asian Vegetable Research and Development Center in 1987, which was superseded by an annotated bibliography in 1992 with 480 abstracts (Chen et al. 1992). These publications provided a summary of most reported research on the disease up to 1991.

Since the discovery of soybean rust in Hawaii in1994, a workshop on soybean rust sponsored, in part, by the United Soybean Board and the Office of Research, College of Agricultural, Consumer and Environmental Sciences, was held August 9–11, 1995, at the National Soybean Research Laboratory, University of Illinois at Urbana Champaign, to further review the situation and make recommendations (Sinclair and Hartman, 1995). The purpose of the workshop was to update current published and unpublished knowledge, discuss the potential threat of the disease to U.S. soybean production, determine research needs and objectives, and suggest management practices for controlling the disease and protecting U.S. soybean production. An executive summary outlining future objectives was produced and some of what was written in that executive summary has been completed, such as the development of rapid molecular identification methods to differentiate the two species (Frederick et

**Figure 2 ■ Urediniospores of the soybean rust pathogen, *Phakopsora pachyrhizi*.**

al. 2002), preparation and distribution of an outreach publication with photographs (Anonymous 2002a), request that USDA Animal and Plant Health Inspection Service Plant Protection Quarantine (APHIS PPQ) prepare an emergency action plan to deal with the possible introduction of soybean rust into the continental United States (Anonymous 2002b), request that effective fungicides be registered for use on soybean to control the disease (some fungicides will be labeled for soybean to control soybean rust in 2003), and establish an international collaborative research effort (United Soybean Board funded project).

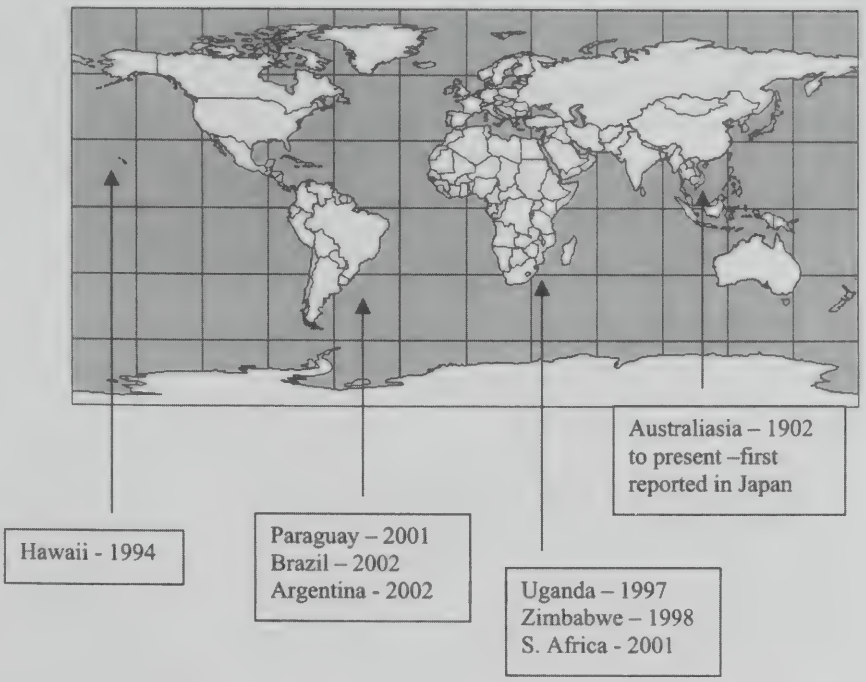



**Figure 3 ■ Distribution of soybean rust *(Phakopsora pachyrhizi).***

Since 1995, a number of other meetings occurred, including an APHIS meeting held early in 2002 to develop an emergency action plan for the United States. Other meetings that took place in 2002 included state meetings in Iowa and Mississippi to develop state action plans, and support meetings between researchers and soybean grower groups. Future events are planned that include a special plenary session on rust at the American Phytopathological Society Meetings in 2002 as well as researchers going to various parts of the world to meet with other researchers in several continents. The geographical expansion of soybean rust will most likely dictate the where and when of future meetings. In addition, the next World Soybean Conference in Brazil in 2004 will have a special session on soybean rust (Yorinori, personal communication).

## DISTRIBUTION

Before 1976, *Phakopsora pachyrhizi* had been well documented in eastern Australia, eastern Asia, and the islands between those land masses, including Japan, The Philippines, and Taiwan (Hartman et al. 1999). In 1976, rust on soybean was discovered in Puerto Rico by N. G. Vakili (USDA–ARS) while examining experimental plantings of legumes at the Adjuntas Agricultural Substation in the Limani Valley (Vakili 1978, Vakili 1979). This report was the first of soybean rust occurring in the Western Hemisphere, although the fungus had been reported on other domesticated and wild legumes. It was acknowledged at the time that the form of rust occurring in the Western Hemisphere was less virulent on soybean than was the Asian form and thus was less of a threat than the Asian form.

On May 4, 1994, soybean rust was detected on a farm in Mililani located in the central part of the island of Oahu (Figure 3) (Killgore and Heu 1994). The Hawaii Department of Agriculture immediately set the stage for emergency action by initiating legal procedures for mandatory eradication of diseased soybean fields. The Department along with USDA APHIS PPQ officials in Honolulu alerted federal plant quarantine officials that advised not setting up a federal quarantine because measures were already in place that prohibited the movement of fresh soybean plant material, including pods from Hawaii. Because the pathogen is not seed transmitted, there was no risk in the export of seed material to the continental United States. As a precaution, they recommended that all seed for export be thoroughly cleaned of any chaff or plant contaminants before shipping. Due to the widespread occurrence of the disease, the emergency status for rust eradication was cancelled.

In 1998, rust was discovered in Zimbabwe and 2 years later in South Africa. The historical distribution of rust in Africa has thoroughly been reviewed (Levy et al. 2002). The next major occurrence of soybean rust occurred in Paraguay in 2001 and in Argentina

and Brazil in 2002 (personal communication and observation). The expansion of soybean rust to other South and Central America has yet to be observed; however, the likelihood of spread to other counties north of Brazil, into Central America and Mexico, has heightened awareness in the United States. Thus, it more likely that an observant grower, crop scout, or other professional who is trained in searching for soybean rust will make the first observation of soybean rust in the continental United States.

## RUST PATHOGENS

The family Phakopsoraceae consist of 12 genera and nearly 200 species of rust worldwide Buritica and Hennen 1994). Two closely related genera infect legumes, *Cerotelium* and *Phakopsora*. Approximately 80 species of *Phakopsora* are known worldwide with six species on leguminous plants. The two species that infect soybean are best identified by traits of the telial sori. The nomenclatural history of these two species is complex and is reviewed by Ono et al. (1992). *P. pachyrhizi* has a telial stage in which the spores are in two to seven layers and the spore walls are pale yellowish brown, and more or less uniformly approximately 1 µm in thickness, or only slightly thickened up to 3 µm in the apical walls of the outermost layer of spores. *P. meibomiae* has telia in which the spores are in one to four, rarely five, layers; the spore walls are cinnamon brown to light chestnut brown, and 1.5 to 2 µm in thickness but with the apical walls of the outermost layer of spores up to 6 µm in thickness.

Several early reports showed the differences between the two species. Bromfield et al. (1980) conducted virulence studies in the plant disease containment facility at Fort Detrick on different soybean rust isolates and showed that the pathogen in Puerto Rico was pathogenically different from the pathogen in Asia and Australia. On all soybean cultivars and germplasm, the Puerto Rican isolate produced a "resistant reaction" also known as an "RB reaction" because of a distinct reddish brown coloration of the lesions. In contrast, the Asian and Australian cultures produced a susceptible (TAN), resistant, or immune reaction, depending on soybean genotype. The differential reactions of the Asian isolate on soybean genotypes showed that pathogenic races of *P. pachyrhizi* existed. In addition, it was demonstrated that the Asian and Puerto Rican cultures differed in appearance of the germ pores (Bonde and Brown 1980) and isozyme patterns (Bonde et al. 1988), and they concluded that two populations were involved in causing rust on soybean.

To complete the story on identification of the soybean rust pathogens, a comprehensive article on the morphology of the phakopsoroid fungi on legumes identified the rust pathogen on soybean in the Western Hemisphere as new species, *P. meibomiae* (Ono et al. 1992). In a recent article (Frederick et al. 2002), a molecular approach was used to distinguish the two species based on nucleotide sequence of the internal transcribed spacer (ITS) region. By using differences within the ITS region, four sets of polymerase chain reaction (PCR) primers were designed specifically for *P. pachyrhizi* and two sets for *P. meibomiae*. Identification of the soybean rust fungi with real-time PCR allows for more rapid diagnoses, occurrence, and distribution of the other two species.

### Host Range

The host ranges of these two species of soybean rust are unusually wide (Chen et al. 1992). *P. meibomiae* has been reported to produce natural infections on 42 species in 19 genera of legumes, and 18 species in 12 additional genera have been artificially infected. *P. pachyrhizi* has been reported to produce natural infections on 31 species in 17 genera of legumes, and 60 species in 26 additional genera have been artifically infected. Twenty-four species in 19 genera are common hosts for both rust species. Among these many legume hosts, *Pueraria* species or kudzu is noteworthy because of its vigorous growth and widespread occurrence in the southeastern states. Kudzu and other species could serve as potential alternative hosts and reservoirs of inoculum.

### Races

Most studies done on race identification were completed more than 20 years ago either at Fort Detrick confinement facilities or at Asian Vegetable Research and Development Center (AVRDC) in Taiwan. Three infection types were described (Bromfield 1984): 1) TAN, tan lesions (0.4 $mm^2$ with 2–4 uredinia per lesion); 2) RB, reddish brown lesions (0.4 $mm^2$ with 0–2 uredinia per lesion) and; 3) 0, absence of macroscopically visible signs or symptoms. In one study (Anonymous 1985), 42 purified isolates were inoculated on Ankur, PI 200492, PI 230970, PI 230971, PI 239871A, PI 239871B, PI 459024 and PI 459025, TK#5, TN#4, and Wayne. Most isolates caused TAN-type lesions on at least seven of the lines and these isolates were classified into nine races. The data suggested that the predominant races

are complex, and these races possess multiple virulence factors for compatibility on most of the lines. The presence of multiple virulence genes in the pathogen population, and the absence of multiple specific resistance genes in the host, could make techniques such as gene rotation and stacking of specific resistance genes ineffective.

## EPIDEMIOLOGY

Because of the paucity of information about soybean rust in the Eastern Hemisphere and the potential danger to soybean production in the continental United States, the U.S. Department of Agriculture, Plant Disease Research Laboratory, and the AVRDC started a cooperative project in 1978 to study the epidemiology of soybean rust. This cooperative project continued until 1982 (Tschanz) and the research on soybean rust continued at AVRDC until 1992. A review of at least some of the AVRDC research was presented at the 1995 Soybean Rust Workshop (Hartman 1995).

### Disease development

Most of the known epidemiology of the two pathogens that cause soybean rust is based on research from *P. pachyrhizi*, the species that predominates in Australasia. There is considerably less research on rust epidemics caused by *P. meibomiae*, and proper documentation on yield losses is lacking. Under field conditions, *P. pachyrhizi* infects soybean leaves early in the season. Precipitation, 6-hour dew periods or longer, and moderate temperatures enhance rust severity. After initial infection, the disease progresses slowly and may take several weeks for urediniospores to increase. Irrigation and precipitation increases rust severity and aids in its spread. Lower leaves often are heavily infected before the upper leaves become infected. The pathogen progresses rapidly from lower to upper leaves when plants begin to flower. At that time, lower leaves senesce earlier than lower leaves on noninfected plants, and heavily infected plants mature up to 2 weeks earlier.

### Potential entry and risk analysis

The pathogens that cause soybean rust could enter into the continental United States in several different ways. One potential avenue is through its continued spread by urediniospores north from field to field through South America, Central America, and to Mexico, representing a land-bridge type of spread. It potentially could come into the United States by way of tropical storms either from equatorial or northern regions in South America or by way of West Africa. It also could be associated with debris imported with seeds, although it has never been found to be associated with seed. Tourists are another possibility because they could potentially bring in spores trapped in their clothes. Importation of alternative hosts is another possible point of contamination. Another potential carrier could be from travels bringing in infected Edamame pods as fresh vegetable soybean.

In terms of risk, the overall conclusion is that the *P. pachyrhizi* poses a greater threat to the continental United States than *P. meibomaie*. If the Asian races were introduced into the continental United States, one should anticipate that significant (>10%) yield losses could occur in nearly all soybean-growing areas, with the greatest losses (up to 50%) in the Mississippi delta and the southeastern coastal areas (Yang 1995). Because of the suitable climate and the presence of alternative hosts, the area most likely for the pathogen to overwinter is the Mississippi delta. A key question is whether the pathogen can overwinter in the continental United States after entry and form a rust reservoir and rust dissemination path. For example, although the conditions for soybean rust development are met as far north as Minnesota, the pathogen may not overseason there, and a new introduction would have to occur each year presumably from spores blown up from the south.

### Disease progress curves

Disease progress curves are used to monitor rust epidemics based on recording severity of rust on leaves over time. These curves are used to obtain values for the area under the disease progress curves that can be used to compare epidemics when studying infection rates; testing soybean lines for their reactions to rust; and testing fungicide efficacy, irrigation, and other factors that effect rust development. The rate of rust development also is dependent on soybean maturation. Later maturing lines often have less rust than earlier maturing lines when evaluated at the same time, because of the differences in soybean maturation. To correct for differences in host maturity, relative lifetime as the time element may partially or completely delete the differences in maturation. Along with assessments of leaf severity, factors such as defoliation and percentage of green leaf area that accounts for defoliation are useful in comparing treatments, whether they are fungicide

applications or tests of different cultivars or lines. Monitoring rust epidemics has provided important information on how the disease develops (Yang et al. 1990, 1991; Hartman et al. 1991). Various schemes for rating rust have been summarized (Hartman 1995), but there is more work that needs to be done in this area that would take advantage of digital imagery and other techniques to monitor disease development.

### Relationship of yield to rust severity

Yield losses of up to 80% have been reported from experimental trials in many countries throughout Asia and in Australia (Figure 4) (Hartman et al. 1999). Heavily infected plants have fewer pods and lighter seed (Hartman et al. 1991, Yang et al. 1991). Marketable yields are even less because of poor seed quality. A number of reports have quantified disease parameters such as leaf severity, defoliation, pustule counts, and area under curves to yield components. A critical point model, using leaf severity at flowering, was shown to be a good predictor of yield loss (Wamontree and Quebral 1984). Several publications have addressed the issue of quantifying disease parameters such as leaf area infected, defoliation, pustule counts, and area under curves to yield components. Yang et al. (1991) regressed the relative area under the disease progress curve to seed growth rates, seed growth periods from R4 to R7 growth stage, and yield. Hartman et al. (1991) regressed leaf area infected at growth stage R6 and the area under the disease progress curve to percentage yield of fungicide-protected plots. In these reports and in others, quantifying disease parameters to yield was effective and with additional information, these data have provided the basis for disease forecasting and yield loss models.

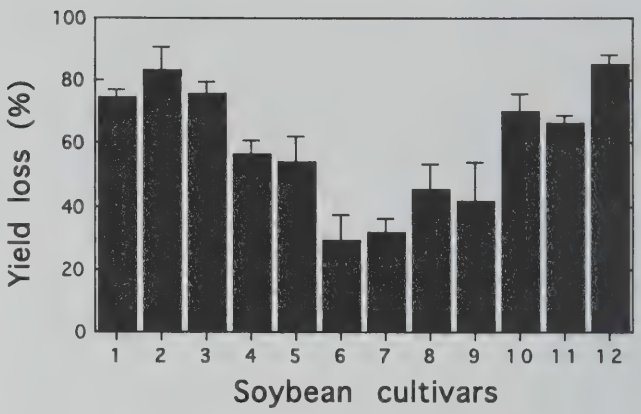



**Figure 4 ■ Yield loss of 12 soybean cultivars based on the difference in yield of plants in plots that were rust infected compared to yields of plants in fungicide protected plots in 1990 in Taiwan.**

## MANAGEMENT

### Specific rust resistance

Four independent dominant gene have been identified and have the designations $Rpp_1$ (PI 200692), $Rpp_2$ (PI 230970), $Rpp_3$ (PI 462312), and $Rpp_4$ (PI 459025) (Bernard 1995, Hartwig 1995). As resistant or immune germplasm was identified, it was used as parents in crosses with the 'Centennial'. $F_1$ plants were grown in the greenhouse at Stoneville and $F_2$ populations were evaluated at Frederick. Because of limited space, minimum size populations were grown. In each case resistance was dominant. Some resistant plants were grown to maturity for progeny testing and line D86-8286 was released. Since the early 1980s the USDA—ARS soybean breeding program at the University of Illinois has been transferring genes for rust resistance from various germplasm sources by means of backcrossing to the adapted soybean 'Williams 82' (Bernard 1995). Testing for rust resistance was done in containment at Fort Detrick on a sample of $F_2$ or $F_3$ plants to identify lines carrying resistance. After $BC_5$, a few true-breeding resistance lines were identified, compared for agronomic traits (e.g., appearance, yield, and maturity) and the most resembling 'William 82' were released as L85-2378 ($Rpp_1$), L86-1752 ($Rpp_2$), and L87-0482 ($Rpp_4$).

### Partial or rate-reducing rust resistance

Rate-reducing resistance has been demonstrated; however, it is difficult to evaluate because the rate of rust development is dependent on soybean development and maturity, and evaluation for this type of resistance is time-consuming and prevents the use of this method for screening large populations. Lines with partial resistance or slow-rusting lines have been identified and characterized based on latent period and the number of uredinia per lesion (Hartman 1995). Further research in this area is needed to determine whether certain partial resistance traits can be quantified accurately and quickly.

### Tolerance to soybean rust

Tolerance is defined herein as the relative yielding ability of plants under stress from rust. To evaluate

the relative yield, comparisons between the same line planted in a fungicide-protected plot and nonfungicide-protected plot is used. Although it requires additional field space, tolerance is assessed once per season, unlike obtaining data for disease progress curves, defoliation, and pustule counts for rate-reducing resistance where multiple assessments are needed. Based on this selection procedure, lines have been selected and screened in rust tolerance trials in Taiwan and Thailand (Hartman 1995, Nuntapunt 1995). Based on percentage increase in yield when comparing lines, there seems to be advanced materials with good levels of tolerance or perhaps when fully characterized, with some partial resistance, too.

### Wild species

In 1975, Singh et al. (1975) reported that under field conditions in India, accessions of *Glycine tabacina* and *Glycine tomentella* were resistant to soybean rust. In Australia, Burdon and Marshall (1981) evaluated the native *Glycine* species for rust resistance. There studies showed there were major genes for resistance (Burdon 1988), and they used the wild species to establish differentials to detect races (Burdon and Speer 1984). Over a 3-year period in Taiwan, 294 accessions representing 12 perennial *Glycine* spp. were screened for resistance to *P. pachyrhizi* (Hartman et al. 1992). Twenty-three percent of the 294 accessions were resistant, whereas 18% were moderately resistant and 58% were susceptible. Resistant or moderately resistant accessions to soybean rust were identified within accessions of *Glycine argyrea, Glycine canescens, Glycine clandestina, Glycine latifolia, Glycine microphylla, Glycine tabacina,* and *Glycine tomentella.*

### Cultural control

A number of other methods need to be considered for a full-scale management program. Most of these practices are in need of further study to evaluate their effectiveness. In the literature (Chen et al. 1992), reports have indicated that date of planting, early- and late-maturing cultivars, density of stand, control of alternative hosts, and tillage or destroying plant debris may have some role in an overall management scheme.

### Chemical control

Information on well-planned economical feasible program for the fugnicide control of soybean rust is not available. For example, the economic threshold of soybean rust is not known, and occurrence and severity of soybean rust vary among regions, from season to season, and even within regions in the same season so that developing exact thresholds may be difficult. The epidemiology of soybean rust is not understood and precise forecasting of soybean rust epidemics is not possible with the present knowledge.

A summary of the most widely used fungicides and the sources of the data are presented in the 1995 Soybean Rust Workshop (Sinclair and Hartman 1995). More recently, fungicides have been tested in Zimbabwe (Levy et al. 2002) with some general recommendations. Approved compounds in Zimbabwe include cyproconazole, difenconazole, flutriafol, flusilazole/carbendazim, tebuconazole, triadimenol, and triforine. In areas of known high rust severity, three sprays are necessary to maintain optimum yields. The first should be applied at first flowering, and the other two at 21-day intervals thereafter. In areas of low rust severity, only two sprays are recommended at first flowering and 21 days later. In general, for effective fungicide control of soybean rust, with any materials so far tested, multiple fungicide applications are required. Thus, spraying with fungicides to control soybean rust will be time-consuming and expensive. Multiple applications of fungicides would pay when losses of 80% are expected, but when losses are less than 10 to 15%, it may be difficult to justify the cost of fungicides. More work must be done on timing, rates, number of times that applications are needed, plant age, and other factors affecting the use of fungicides for control of this disease. During the next growing season (2002–2003) in Brazil and Paraguay, there will be numerous fungicide trials to provide data on efficacy of products as well as rates and timing. This information will form the basis for obtaining labeling of fungicides for use in the United States.

## CONCLUSION

Although rust is not in the continental soybean-producing region in the United States, its recent movement to areas where it has not been reported before (Hawaii, some countries in Africa and South America within the last decade, or in some areas within the past year) makes it even more likely that at some time it will enter the continental Unites States. In the past year, there have been several meetings addressing issues related to soybean rust, and this exposure has helped USDA to formulate an

Action Plan that has responses that include stakeholder communication, education, and training; potential detection methods and alternatives; and mitigation measures to reduce the impact on U.S. soybean growers once soybean rust is found in continental U.S. growing areas. Management tools such as developing resistant varieties and fungicide registrations are both being pursued and will serve as the primary focus on management of soybean rust.

## REFERENCES


Anonymous. 1985. Annual report, AVRDC, 1983. Shanhua, Tainan, Taiwan, Republic of China: Asain Vegetable Research and Development Center.

Anonymous. 2002a. Pest alert: Soybean rust USDA, APHIS, Plant Protection Quarantine, 2002 [cited 2002]. Available from http://www.aphis.usda.gov/ppq/ep/pestdetection/soybean_rust/soybeanrust.html.

Anonymous. 2002b. Strategic plan to minimize the impact of the introduction and establishment of soybean rust on soybean production in the United States: USDA, Marketing and Regulatory Programs, APHIS-PPQ.

Bernard, R.L. 1995. Rust resistant isolines developed at the University of Illinois at Urbana-Champaign. Pages 68 in: Proceedings of the Soybean Rust Workshop, 9–11 August 1995, J.B. Sinclair and G.L. Hartman, eds. National Soybean Research Laboratory Publication Number 1, Urbana, IL.

Bonde, M.R., and Brown, M.F. 1980. Morphological comparison of isolates of *Phakopsora pachyrhizi* from different areas of the world. Can. J. Microbiology 26: 1443–1449.

Bonde, M.R., and Peterson, G.L. 1995. Research at the USDA, ARS Containment Facility on soybean rust and its causal agent. Pages 68 in: Proceedings of the Soybean Rust Workshop, 9-11 August 1995, J.B. Sinclair and G.L. Hartman, eds. National Soybean Research Laboratory Publication Number 1, Urbana, IL.

Bonde, M.R., Peterson, G.L., and Dowler, W.M. 1988. A comparison of isozymes of *Phakopsora pachyrhizi* from the Eastern Hemisphere and the New World. Phytopathology 78: 1491–1494.

Bromfield, K.R. 1984. *Soybean Rust, Monograph (American Phytopathological Society), no 11*. St. Paul, MN: American Phytopathological Society.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Bromfield, K.R., Melching, J.S., and Kingsolver, C.H. 1980. Virulence and aggressiveness of *Phakopsora pachyrhizi* isolates causing soybean rust. Phytopathology 70: 17–21.

Burdon, J.J. 1988. Major gene resistance to *Phakopsora pachyrhizi* in *Glycine canescens*, a wild relative of soybean. Theor. Appl. Genet. 75: 923–928.

Burdon, J.J., and Marshall, D.R. 1981. Evaluation of Australian native species of *Glycine* for resistance to soybean rust. Plant Dis. 65: 44–45.

Burdon, J.J., and Speer, S.S. 1984. A set of differential *Glycine* hosts for the identification of races of *Phakopsora pachyrhizi* Syd. Euphytica 33: 891–896.

Buritica, P., and Hennen, J. 1994. familia Phakopsoraceae (Uredinales). 1. generos anamorficos y teleomorficos. Rev. Acad. Colombiana Ciencias Exactas, Risicas, y Naturales 19: 47–62.

Chen, F.C., MacIntyre, R., and Lopez, K. 1992. *Annotated bibliography of soybean rust (Phakopsora pachyrhizi Syd.)*. Vol. 4-1, *AVRDC library bibliography series*. Taipei: Asian Vegetable Research and Development Center, Tropical Vegetable Information Service.

Ford, R.E., and Sinclair, J.B. 1977. Rust of soybean - the problem and research needs, February 28–March 4, Manila, The Philippines.

Frederick, R.D., Snyder, C.L., Peterson, G.L., and Bonde, M.R. 2002. Polymerase chain reaction assays for the detection and discrimination of the soybean rust pathogens *Phakopsora pachyrhizi* and *P. meibomiae*. Phytopthology 92: 217–227.

Hartman, G.L. 1995. Highlights of soybean rust research at the Asian Vegetable Research and Development Center. Pages 68 in: Proceedings of the Soybean Rust Workshop, 9–11 August 1995, J.B. Sinclair and G.L. Hartman, eds. National Soybean Research Laboratory Publication Number 1, Urbana, IL.

Hartman, G.L., Wang, T.C., and Tschanz, A.T. 1991. Soybean rust development and the quantitative relationship between rust severity and soybean yield. Plant Dis. 75: 596–600.

Hartman, G.L., Wang, T.C., and Hymowitz, T. 1992. Sources of resistance to soybean rust in perennial Glycine species. Plant Dis. 76: 396–399.

Hartman, G.L., Sinclair, J.B., and Rupe, J.C., eds. 1999. *Compendium of Soybean Diseases*, 4th ed. St. Paul: American Phytopathological Society.

Hartwig, E.E. 1995. Resistance to soybean rust. Pages 68 in: Proceedings of the Soybean Rust Workshop, 9-11 August 1995, J.B. Sinclair and G.L. Hartman, eds. National Soybean Research Laboratory Publication Number 1, Urbana, IL.

Killgore, E. 1995. Field notes on the detection of soybean rust, initial surveys and the current status of the disease in Hawaii. Pages 68 in: Proceedings of the Soybean Rust Workshop, 9-11 August 1995, J.B. Sinclair and G.L. Hartman, eds. National Soybean Research Laboratory Publication Number 1, Urbana, IL.

Killgore, E., and Heu, R. 1994. First report of soybean rust in Hawaii. Plant Dis. 78: 1216.

Levy, C., Techagwa, J.S., and Tattersfield, J.R. 2002. The status of soybean rust in Zimbabwe and South Africa. Paper read at Special Workshop on Soybean Rust, II Brazilian Soybean Congress, 3–6 June, 2002, at Foz do Iguaçu, Paraná, Brazil, 3–6 June, 2002.

Nuntapunt, M. 1995. Soybean projects in Thailand (1985-1995). Pages 68 in: Proceedings of the Soybean Rust Workshop, 9–11 August 1995, J.B. Sinclair and G.L. Hartman, eds. National Soybean Research Laboratory Publication Number 1, Urbana, IL.

Ono, Y., Buritica, P., and Hennen, J.F. 1992. Delimitation of *Phakopsora, Physopella* and *Cerotelium* and their species on Leguminosae. Mycol. Res. 96: 825–850.

Sinclair, J.B., and Hartman, G.L. 1995. Proceedings of the Soybean Rust Workshop, 9–11 August 1995. Paper read at National Soybean Research Laboratory publication, at Urbana, IL.

Singh, B.B., Gupta, S.C., and Singh, B.D. 1975. Sources of field resistance to rust [Phakopsora pachyrihizi] and yellow mosaic diseases of soybean. Indian J. Genet. Plant Breed. 34: 400–404.

Tschanz, A.T. 1982. Soybean Rust Epidemiology. Shanhua, Tainan, Taiwan: Asain Vegetable Research and Development Center.

Vakili, N.G. 1978. Proceedings of the Workshop on Soybean Rust in the Western Hemisphere : November 14–17, 1976, Mayaguez, Puerto Rico.

Vakili, N.G. 1979. Field survey of endemic leguminous hosts of *Phakopsora pachyrhizi* in Puerto Rico. Plant Dis. Rep. 63:931-935.

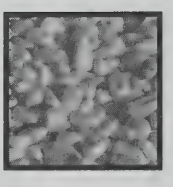
Wamontree, L.E., and Quebral, F.C. 1984. Estimating yield loss in soybeans due to soybean rust using the critical point model. Philippine Agriculturist 67: 135–140.

Yang, X.B. 1995. Assessment and management of the risk of soybean rust. Pages 68 in: Proceedings of the Soybean Rust Workshop, 9–11 August 1995, J.B. Sinclair and G.L. Hartman, eds. National Soybean Research Laboratory Publication Number 1, Urbana, IL.

Yang, X.B., Dowler, W.M., and Tschanz, A.T. 1991. A simulation model for assessing soybean rust epidemics. J. Phytopathol. 133: 187–200.

Yang, X.B., Royer, M.H., Tschanz, A.T., and Tsai, B.Y. 1990. Analysis and quantification of soybean rust epidemics from seventy-three sequential planting experiments. Phytopathology 80: 1421–1427.

Yang, X.B., Tschanz, A.T., Dowler, W.M., and Wang, T.C. 1991. Development of yield loss models in relation to reductions of components of soybean infected with *Phakopsora pachyrhizi*. Phytopathology 81: 1420–1426.



# CURRENT AND FUTURE PROSPECTS FOR BIOLOGICAL CONTROL OF INVASIVE WEEDS IN ILLINOIS

**Robert N. Wiedenmann**

Invasive species are a part of the everyday lives of all of us. Invasive species have made major inroads into nearly every type of habitat, from forests to wetlands, agricultural fields to prairies, the Great Lakes to our great rivers. Invasive species are represented by all kinds of organisms, including fish (e.g., round goby [*Neogobious melanostomus*] and common carp [*Cyprinus carpi*]), insects (e.g., Asian longhorned beetle [*Anoplophora glabripennis*] and soybean aphid [*Aphis glycines*]), or species such as the zebra mussel (*Dreissena polymorpha*). But certainly some of the most noticeable and problematic are invasive weeds.

First some terminology: invasive and exotic are not the same terms, although they are often incorrectly interchanged. Not all exotic species are invasive; not all invasive species are exotic. Consider soybean or alfalfa, both of which came to North America from exotic places, yet are important and beneficial to agriculture. However, the native poison ivy (*Toxicodendron radicans*) can clearly be labeled as invasive. Even desirable native plants, such as sugar maple, can be considered invasive in certain habitats or settings. But the majority of invasive species are exotic. Of the greater than 2,100 species of plants considered weeds in North America, roughly 1,365 (65%) are exotic species (Westbrooks 1998).

There are differences between exotic and native species in how they become invasive. Native species have always been here, but due to some change in habitat, management regimen or genetic change in the species, they are able to outcompete their neighbors and grow unchecked (DeLoach 1991). Exotic species come from some "exotic" place and have been transported to their new locale, whether accidentally or intentionally. The reason that many exotic species become invasive is that, when they are transported here, their ancestral natural enemies—those biotic factors that kept the populations in check in their native habitats—are not transported with them. All species are under some degree of natural control in their native habitat. When freed of those predators (or herbivores), diseases or even competitors, species can grow unchecked and reach densities that lead to us calling them pests.

Invasive species carry with them great economic costs. Although calculating exact costs may be considered to be an art, a recent study (Pimentel et al. 2000) estimated that invasive species in the United States cost us more than $137 billion per year, due to losses and control costs. This figure, although sometimes criticized, at least offers an estimate of costs, and the study from which the figure was derived represented the best, complete analysis of the many costs due to invasives. Whether the figure is accurate is not the point; invasive species cost all of us money, and large sums of money at that.

Invasive species also carry with them ecological and evolutionary costs. Roughly 40% of the species listed as threatened or endangered in the United States are considered to have been imperiled, at least in part, by invasive species (Wilcove et al. 1998). Furthermore, 40% of the extinct vertebrate species, for whom the causes of extinction are known, were driven extinct, at least partly, by invasive species. Invasive weeds can change habitats, communities, and basic ecological processes. European cheatgrass (*Bromus tectorum*), an invasive weed of the western United States, has altered the habitat so severely that the increased frequency of fires has limited the species that can

survive in those invaded habitats (Kurdila 1995, Vitousek 1996).

Controlling invasive weeds requires a multifaceted, integrated approach. Often, cultural or mechanical approaches, such as burning, cultivating or hand-pulling, can limit populations of invasive weeds, especially new infestations. Herbicides can be effective against some weeds, but other weeds are not harmed by the chemical approach. Biological control often represents the last best hope against some of these invaders.

## BIOLOGICAL CONTROL OF WEEDS

Biological control of exotic, invasive weeds involves reuniting an exotic plant with its natural enemies from the ancestral home of the plant, where it likely is not a weed, due to the effects of the natural enemy. Consulting the literature to find the ancestral home is the first start toward finding a natural enemy. Often a plant has made several stops along the way to its current new home. For example, a weed from central Asia may have been transported first to eastern Europe, and then to a Mediterranean country, and on to the Midwest. Searching in any of the way-stops will most likely not be effective, because the plant did not coevolve with any herbivores or pathogens there; those long-term natural enemies from the ancestral home offer the best chance for controlling the weed in its new habitat.

Once the ancestral home is located (not a trivial task), searching for natural enemies can begin. Even when the suite of natural enemies is found, prioritizing which of these species may impact the invader in the new habitat is not easily achieved. Although identifying which of the natural enemies impact the plant in the ancestral setting is likely to predict how a natural enemy may affect the weed in its new setting, this relationship is not always realized. Still, of the many species that may feed on, or attack, a plant in its native setting, only a much smaller subset is likely to be important, either by attacking seeds or roots, or by being found consistently across different sites or throughout the native range of the plant. Ecological studies in the native habitat are necessary to determine which agents should be pursued through serious study.

After selecting one or more natural enemies to consider as potential agents, the most critical step is to test the specificity of those agents. Host specificity testing ensures that the agent will have a sufficiently narrow host range—those species the agent can attack and exploit—so as to minimize its effects on other, nontarget species. In my view, biological control of weeds has been very safe over its existence (but see Simberloff and Stiling 1996 for a differing opinion), but well-designed experiments to test specificity (McEvoy 1996) are critical to ensure the continued safety of weed biological control.

## INVASIVE WEEDS IN ILLINOIS

Illinois is infested by many problematic weeds, whether in agricultural or more natural habitats. Although several of these are targets of biological control agents—or are being considered for future biological control projects—not all species are equally likely to be pursued. In this article, I mention several species that have not been (or have not yet been) targets of biological control, some future targets, and an ongoing project against purple loosestrife.

### Weeds Not Targeted

Autumn olive (*Elaeagnus umbellata*) is a woody weed species affecting many grazing, roadside, and even prairie areas. Yet, to my knowledge, this shrub has never been the target of biological control, although I am asked repeatedly about its potential for biological control. Reed canary grass (*Phalaris arundinacea*), a weed of wetlands and roadside ditches and waterways, also has not been the target of biological control, despite the interest from many land managers. Dame's rocket (*Hesperis matronalis*), an intentionally planted species along many roadsides, is likely to be a future prospect for biological control, but not any time in the near future and probably not until it is more widely recognized for its invasiveness. Kudzu (*Pueraria lobata*), although a target of biological control efforts with herbivores in the southeastern United States, has not been approached in the Midwest. Efforts to attack kudzu with herbicides and cutting are costly and difficult to maintain over time (McClain et al. 2002), which would suggest that kudzu ought to be considered a potential target for biological control. Biological control agents are being used successfully against leafy spurge (*Euphorbia esula*) in the upper Midwest (Anderson et al. 2000). This weed grows in northwestern Illinois and should be watched for population growth. If its populations spread, the agents being used against spurge in the Dakotas and Montana should be considered for use in Illinois.

### Weeds to Be Revisited or Targeted in the Future

Two weeds—one of long standing in the state, another soon to arrive—that have not previously been the targets of biological control, are currently being studied. Mile-a-minute weed (*Polygonum perfoliatum*), a native to Asia, is moving rapidly westward from the Eastern United States and is anticipated to be a serious pest in Illinois, especially in moist habitats. The insects associated with this plant in China are under study (Jianquing et al. 2000). That study may position us to respond once the weed extends its reach into the Midwest. Canada thistle (*Cirsium arvense*), a problem weed in pasture and natural areas, is the target of studies (Bailey et al. 2000) on fungal and bacterial agents. Finding an agent against this troublesome thistle would be welcomed throughout the state.

Another weed that has been in the state for a long time, musk thistle (*Carduus nutans*), has been the focus of biological control importation in the past in Illinois, the Midwest, and the Great Plains (Louda et al. 1997). Most efforts have focused primarily on the seed-head weevil (*Rhinocyllus conicus*) and to a lesser degree with a rosette weevil (*Trichosirocalus horridus*) (Kok and Surles 1975, DeLoach 1991). This project has attracted great attention, because *R. conicus* also has been found to attack the threatened native Platte thistle (*Cirsium canescens*) in Nebraska (Louda et al. 1997). Depending on one's point of view, either this nontarget attack is an indictment of biological control, because the weevil attacks a native species; or it illustrates the viability of host-specificity testing, because Platte thistle was predicted to be attacked more than 30 yr ago in the original host-specificity testing. Read the wealth of literature on this subject and form your own opinion. In Illinois, success with biological control of musk thistle has been spotty at best, and further work is definitely warranted, whether through augmenting the rosette weevil or seeking other known specific agents.

Two other weed projects are anticipated in Illinois in the near future. Teasel species (*Dipsacus laciniatus* and *D. fullonum*) are becoming much more prominent throughout Illinois but are especially visible along highways (Solecki 1991). Studies on North American herbivores have not yet been done, but personal observation has not shown any effects of herbivores in Illinois. Teasel is expanding beyond its roadside haunts into prairie and uncultivated land, where it may affect native plants (Huenneke and Thomson 1995), making it a target of interest to a broader swath of land managers. One of the most appealing aspects of considering teasel as a target is that the entire family Dipsacaceae is exotic, meaning there are no close relatives. Even though no close relatives exist, the same range of host specificity testing will be required. The United States Department of Agriculture–Agricultural Research Service (USDA–ARS) European Biological Control Laboratory in Southern France has identified teasel as a species to focus efforts on in the next few years.

Another European weed, garlic mustard (*Alliaria petiolata*), will be a near-term target for biological control. Ongoing studies in Switzerland by CABI Bioscience have identified several weevils collected from garlic mustard in Europe (Blossey et al. 2001, Gerber et al. 2002). These weevils of the genus *Ceutorhynchus* attack several different parts of the biennial plant: two weevil species (*C. constrictus* and *C. theonae*) attack seeds, two species (*C. roberti* and *C. alliariae*) mine the shoots, and one species (*C. scrobicollis*) mines the root crown; a flea beetle (*Phyllotreta ochripes*) was found to have a broad host range and was dropped from further consideration (Gerber et al. 2001). Extensive host-specificity testing is underway, because of the many closely related crucifers, and several of the weevils seem to be promising candidates for importation. Once imported to Illinois, however, these weevils will be scrutinized further against a broader range of native crucifers before permission to release the agents will be sought.

## SIGNS OF SUCCESS AGAINST THE WETLAND WEED PURPLE LOOSESTRIFE

Purple loosestrife (*Lythrum salicaria*) is another European invader that has been in North America since the early 1800s. Purple loosestrife is an invader of wetlands, turning once-thriving habitats into a sea of beautiful purple. But the vivid beauty is deceptive—the near monotypic stands of loosestrife make life difficult for native plants and animals that rely on wetlands. Vast stands of loosestrife defy most control efforts. Hand-pulling works only in the smallest stands, when the plant first arrives. Sometimes, flooding can keep loosestrife from germinating, but many of the worst loosestrife infestations in Illinois are in standing water. Burning is not effective. Aboveground stems and foliage die every winter anyway, so fire only burns those parts that are already dead; furthermore, solid stands of loosestrife

do not burn well. Application of herbicides to large infestations is impractical and costly, may be effective only in the smallest stands, and must be continued for years. In fact, both burning and use of a herbicide may be counterproductive: at some sites, we have seen where burning or using a herbicide has led to worse loosestrife infestations. The lack of options is why biological control has been welcomed— it's the only alternative.

Since 1994, two species of leaf-feeding beetles (*Galerucella calmariensis* and *G. pusilla*) have been reared and released throughout Illinois. As of the end of 2002, more than 2.1 million *Galerucella* have been distributed to more than 230 major sites in the state, primarily in northeastern Illinois. This project has been led by scientists at the Illinois Natural History Survey, in partnership with numerous forest preserve and conservation districts, park districts and nature centers, federal agencies, and the Illinois Department of Natural Resources. In addition, we have trained more than 300 educators throughout the state about invasive plants and their control and provided them with materials and support to grow loosestrife and beetles in their classrooms (Post et al. 2002). As a spin-off from this education project, students have gone home and told their parents what they are doing in the classroom, and we have helped the parents raise beetles in their own backyards.

The project is showing signs of success at a number of sites in northern Illinois. At a wetland between two railroad yards in Savanna, large-scale emergence of beetles in 1997 and 1998 led to major defoliation of the plants, with dispersal of the beetles to more than a mile away. However, major spring floods in 2001 and 2002 have further scattered the beetles, leading to a rebound of the weed. The next few years will be interesting, as the beetles find their way back to the wetland. At a site near Illinois Beach State Park, we have been monitoring weed flowering and beetle damage (Figure 1), by categorizing plants as either undamaged (no reduction of flowering), damaged but recovered (fewer, smaller flowering spikes on lateral shoots), or damaged with no recovery (no flowers). The pattern shows that flowering has been reduced and the proportion of undamaged plants remains low. There are still loosestrife plants there, and some of them do flower, but loosestrife would not be considered a weedy pest at the site. At another site, the Weingart Road Sedge Meadow Nature Preserve (in McHenry County), a different kind of effect has been seen. Instead of a large emergence of beetles and massive defoliation, we have seen a gradual reduction of flowering to the point that no flowering has been seen at the site since 1999. Native plants that had been found only infrequently now are more common and outcompete the loosestrife. This same phenomenon has been seen at a few other botanically rich and diverse sites. Ultimately, this gradual reduction is likely to be more sustainable, rather then the boom-and-bust response, as seen at Savanna and other less diverse sites.

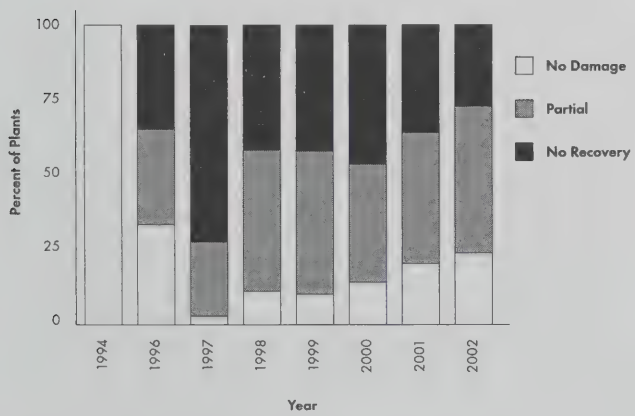



**Figure 1 ■ Percentage of purple loosestrife either damaged with no recovery (no flowering); partial damage (reduced flowering on laterals), or undamaged (full flowering) at Hosah Prairie Nature Preserve, IL, from 1994 to 2002. Biological control agents were released in 1994.**

Biological control, when supported by sound science, can be practiced safely and effectively and provide long-term control of some of our more serious weeds. The success with purple loosestrife gives us hope for the upcoming projects to be conducted against garlic mustard and teasel. The successes here and elsewhere also suggest that biological control should be a more-prominent approach to long-term weed management of some of the other exotic invaders.

## REFERENCES

Anderson, G. L., E. S. Delfosse, N. R. Spencer, C. W. Prosser, and R. D. Richard. 2000. Biological control of leafy spurge: an emerging success story, pp. 15–25. In: N. R. Spencer, ed. Proceedings of the X International Symposium on Biological Control of Weeds, 4–14 July 1999, Bozeman, MT: Montana State University.

Bailey, K. L., S. M. Boyetchko, J. Derby, W. Hall, K. Sawchyn, T. Nelson, and D. R. Johnson. 2000. valuation of fungal and bacterial agents for biological control of Canada thistle, pp. 203–208. In: N. R. Spencer, ed. Proceedings of the X International Symposium on

Biological Control of Weeds, 4–14 July 1999, Bozeman, MT: Montana State University.

Blossey, B., V. Nuzzo, H. L. Hinz, and E. Gerberr. 2001. Developing biological control of *Alliaria petiolata* (M. Bieb.) Cavara and Grande (garlic mustard). Natural Areas Journal 21: 357–367.

DeLoach, C. J. 1991. Past successes and current prospects in biological control of weeds in the United States and Canada. Natural Areas Journal 11: 129–142.

Gerber, E., H. L. Hinz, N. Guazzone, J. McKenney, S. Michler, and M. Zuefle. 2002. Biological control of garlic mustard, *Alliaria petiolata* (Bieb.) Cavara & Grande, Annual Report 2001. Unpublished report, CABI Bioscience Switzerland Centre, Delemont, Switzerland.

Huenneke, L. F., and J. K. Thomson. 1995. Potential interference between a threatened endemic thistle and invasive nonnative plant. Conservation Biology 9: 416–424.

Jianquing, D., F. Weidong, Y. Wu, and R. C. Reardon. 2000. Insects associated with mile-a-minute weed (*Polygonum perfoliatum* L.) in China: a three-year survey report, pp. 225–231. In: N. R. Spencer, ed. Proceedings of the X International Symposium on Biological Control of Weeds, 4–14 July 1999, Bozeman, MT: Montana State University.

Kok, L. T. and W. W. Surles. 1975. Successful biological control of musk thistle by an introduced weevil, *Rhinocyllus conicus*. Environmental Entomology 4: 1025–1027.

Kurdila, J. 1995. The introduction of exotic species into the United States: there goes the neighborhood. Environmental Affairs 16: 95–118.

Louda, S. M., D. Kendall, J. Connor, and D. Simberloff. 1997. Ecological effects of an insect introduced for the biological control of weeds. Science 277: 1088–1090.

McClain, W., J. E. Ebinger, J. Shimp, and T. Esker. 2002. Getting a hold on kudzu before it gets a hold on us. Illinois Steward 11: 25–28.

McEvoy, P. B. 1996. Host specificity and biological pest control. BioScience 46: 401–405.

Pimentel, D., L. Lach, R. Zuniga, and D. Morrison. 2000. Environmental and economic costs of nonindigenous species in the United States. BioScience 50: 53–65.

Post, S. L., R. N. Wiedenmann, M. R. Jeffords, and D. Voegtlin. 2002. The color purple: an education program about exotic species. Illinois Steward 11: 19–24.

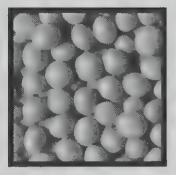
Simberloff, D., and P. Stiling. 1996. How risky is biocontrol? Ecology 77: 1965–1974.

Solecki, M. 1991. Cut-leaved and common teasel (*Dipsacus laciniatus* L. and *D. sylvestris* Huds.): profile of two invasive aliens, pp. 85–92. In: B. McKnight, ed. Biological Pollution: The Control of Impact of Invasive Exotic Species. Indianapolis: Indiana Academy of Science.

Vitousek, P. M., C. M. D'Antonio, L. L. Loope, and R. Westbrooks. 1996. Biological invasions as global environmental change. American Scientist 84: 468–478.

Westbrooks, R. G. 1998. Invasive plants : changing the landscape of America : fact book. Federal Interagency Committee for the Management of Noxious, Washington, DC.

Wilcove, D. S., D. Rothstein, J. Dubow, A. Phillips, and E. Losos. 1998. Quantifying threats to imperiled species in the United States. BioScience 48: 607615.



# WEST NILE VIRUS: AN IPM CHALLENGE IN ILLINOIS

**Robert J. Novak and Richard L. Lampman**

## INTRODUCTION

West Nile Virus (WNV) is considered the most significant insect-borne disease affecting the health of humans and animals in recent U.S. history. Unlike most other mosquito-borne diseases that endanger humans, WNV also causes severe illness and death in horses and wildlife, especially birds. In North America to date, WNV has been found in at least 111 bird species, including endangered, game, nongame, and domestic species. WNV has been isolated from 29 species of mosquitoes (18 of which are found in Illinois), and two species of ticks. These mosquitoes include both floodwater species, which are primarily pests that occur in high numbers throughout the summer, as well as foul-water mosquitoes that are known to transmit diseases to both humans and animals. Recently, WNV has been isolated from "owl keds" (Hippoboscidae), species-specific ectoparasites of owls (Novak, unpublished data). In humans, WNV causes debilitating symptoms that are life threatening to the elderly and those individuals with weakened immune systems. There is no vaccine or cure. The only effective prevention is early detection in birds or mosquitoes, followed by quick environmentally sound mosquito control. Quick control requires rapid detection, identification, coordination, and information given to public health and mosquito/vector control managers.

The objectives of this article is to 1) provide a current update of the epidemic of West Nile virus in Illinois and its impact on humans, wildlife, and domestic animals; 2) provide an explanation of how integrated pest management (IPM) principals and tactics are defined and used to manage a vector-borne disease; and 3) provide a strategy for early detection and interdiction to minimize transmission of WNV based on the Champaign-Urbana-Savoy-University model program.

## SYNOPSIS OF WEST NILE VIRUS EPIDEMIC IN ILLINOIS, 2001–2002

WNV first entered Illinois in 2001 in northern Illinois from approximately 140 corvids (American crows and blue jays) and raptors, 20 pools of mosquitoes, and two horses (1). Within 1 year, Illinois had the highest number of human cases (700) and deaths (43) in the United States, exceeding the 1975 epidemic of St. Louis encephalitis virus (Monath 1988). In 2002, West Nile virus transmission was detected in 98 of 102 counties in Illinois based on viral identifications from mosquitoes (528 WNV-positive pools), birds (513 WNV-positive dead birds), and horses (1000). The Illinois Department of Public Health reported that in 2002 human cases were distributed among 46 counties. Cook County, which comprises about 40% of human population in Illinois, had 501 confirmed cases and 24 fatalities.

Figure 1 presents a diagrammatic view of the possible transmission cycle of West Nile virus in Illinois, as we understand it to date, and gives a visual view of the interaction of mosquitoes, the human host, and the mammal host. It is important to remember that this virus moved into Illinois and the Midwest east to west, which is different from St. Louis encephalitis virus (SLEV) that arrives in the Midwest largely with spring bird migration. It is possible that American crows could have moved the virus along this west-

ward track because these birds can fly long distances. West Nile virus also kills American crows in approximately 7 days from initial inoculation. However, these birds do not start to show signs of infection until approximately day 4, which gives them ample opportunity to move around. One of the first symptoms exhibited by infected crows is their inability to move, which leave them venerable to mosquitoes seeking blood meals. What role the other 111 species of bird play in to spread or maintenance of WNV is still unknown. We still do not know how many of these other bird species are responding to WNV infection and whether they are capable of producing sufficient antibody protection.

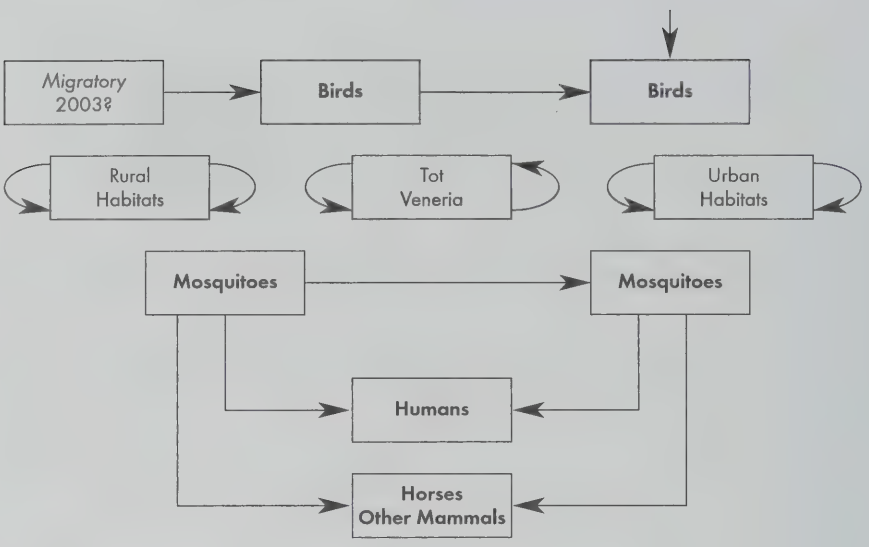



**Figure 1 ■ Diagrammatic scheme of West Nile virus transmission cycle in Illinois.**

Mosquito samples collected from northern, central, and southern Illinois and analyzed for WNV by *TaqMan* reverse transcriptase-polymerase chain (*TaqMan* RT-PCR) reaction revealed the magnitude and pervasiveness of epidemic throughout the state. Two new *Culex* species were found to be positive for WNV, as was pooled samples of male mosquitoes from three genera. Research collections from throughout the state identified WNV in 10 mosquito species by October 1, 2002. The number of species positive for WNV seemed to follow a latitudinal gradient with increasing species diversity the further south collections were made. In northern Illinois, WNV was detected in *Aedes vexans, Culex restuans, Culex pipiens,* and mixtures of the two *Culex* species. In central Illinois, WNV was found in pools of *Ae. vexans, Anopheles punctipennis, Anopheles quadrimaculatus, Uranotaenia sapphirina, Cx. pipiens,* and a mixture of *Cx. pipiens* and *Cx. restuans*. In southern Illinois, WNV-positive pools included batches of *Ae. vexans, Anopheles crucians, An. punctipennis, An. quadrimaculatus, Aedes albopictus, U. sapphirina, Culex erraticus, Culex territans,* and a mixture of *Cx. pipiens* and *Cx. restuans*. This report seems to be the first of WNV being isolated from *Cx. territans* and *Cx. erraticus*. The most frequent WNV positives were from pools of *Cx. pipiens* and *Cx. restuans,* as well as a mixture *Culex* species in the subgenus *Culex*. Surprisingly, there were also multiple detections of WNV in *Ae. vexans, An. punctipennis, An. quadrimaculatus,* and *Ae. albopictus*.

Male mosquitoes from at least four species were also positive by *TaqMan* RT-PCR, which is evidence of vertical transmission either by venereal or transovarial transmission. With vertical transmission, the virus can be moved from mother to offspring via the eggs and subsequent larvae and pupae, and from males to females through mating. Four pools of males from *Culex* (subgenus *Culex*) species, possibly a mixture of *Cx. restuans* and *Cx. pipiens*, were positive; three pools from Champaign County and one from Cook County. Two pools of *An. quadrimaculatus* males were WNV positive; one pool each from Jackson and Champaign counties. One pool each of *An. punctipennis* and *Ae. albopictus* males collected in Saline County were also WNV positive. Vertical transmission was previously reported by Miller et al. (2000) in field-collected *Cx. univittatus* males in Kenya and the potential for transovarial transmission was demonstrated under laboratory conditions for *Ae. albopictus, Ae. vexans, Ae. aegypti, Ochlerotatus atropalpus, Ochlerotatus japonicus, Ochlerotatus taeniorhynchus, Cx. pipiens, Cx. vishnui,* and *Cx. tritaeniorhynchus* (Baqar et al., 1993, Turell 2000, Mishra et al. 2001, Turell et al. 2001). However, the Illinois Natural History Survey (INHS) Medical Entomology Laboratory (unpublished data) is the first to detect multiple species of field-collected WNV-positive males as well as the first to document vertical transmission of WNV in two *Anopheles* species.

Transmission of WNV in Illinois spilled over into numerous animals besides birds (corvids and raptors), humans, and mosquitoes. Almost 1,000 horse

cases were reported in Illinois (3) and *TaqMan* RT-PCR analysis in our laboratory detected WNV in dog, wolf (Lichtenstieger et al. 2002), and squirrel brains. We also found a hippoboscid (*Icosta* sp.) from a great horned owl was WNV positive. To date, a blocking IgG enzyme-linked immunosorbent assay (Blitvich et al. 2002) on sera from 245 live birds from 49 species has found 11 samples positive for WNV antibody. In northern Illinois, Cook County had a positive juvenile American robin from River Trails Nature Center collected on August 27. In central Illinois, WNV antibodies were detected in two gray catbirds (*Dumatella carolinensis*), two American robins (*Turdus migratorius*), and one brown thrasher (*Toxostoma rufum*) collected August 1. Champaign County also had three WNV antibody-positive domestic chickens collected on August 12 and September 13. In southern Illinois, Williamson County had a positive juvenile green heron (*Butorides virescens*) collected on August 22. The presence of West Nile virus in such biologically diverse species suggests intense transmission.

The complexity of developing a statewide IPM program to minimize the impact of WNV on humans, domestic, and wild animals can easily be understood by the diversity in vector species (mosquitoes and ectoparasites?), bird reservoir hosts, and nonhuman mammalian hosts. Although it also might be assumed that WNV transmission spread from northern to southern counties based on the aggregation and abundance of human cases in Cook County, positive mosquito pools from throughout Illinois were detected about the same time in early to mid-July. This information suggests multiple WNV outbreaks occurred in northern, central, and southern Illinois.

The magnitude and pervasiveness of these outbreaks was demonstrated by 1) a more than 50% WNV-positive prevalence in *Culex* pools from northern Illinois in late July through August, 2) the number of mosquito species positive for WNV, 3) the detection of WNV-positive male mosquitoes, and 4) the involvement of numerous incidental and atypical hosts. The number of WNV-infected mosquito species seemed to increase along a north to south gradient, suggesting a greater potential for the involvement of bridge vectors and hosts in southern Illinois, particularly because several of the WNV-positive species are considered to be avid mammal feeders (i.e., *Ae. albopictus*, *Ae. vexans*, *An. quadrimaculatus*, and *An. punctipennis*). This behavior indicates that IPM models or strategies must be individually tailored to address the specific ecological characteristics throughout the state.

## PRINCIPALS OF IPM FOR VECTOR MANAGEMENT

The concepts and practices of IPM, which were largely developed in response to crop pests, turned out to be readily adaptable to arthropod public health pests (Metcalf and Novak 1994, Dent 1995, Kogan 1998) and should provide the basis for emergency management tactics such as the epidemic of WNV. The initial step in vector management is to identify and define, as best as possible, the components of the pest management unit for a specific area. Once the transmission cycle of the pathogen and the life histories of the vector, host, and reservoir or maintenance species are identified, the cornerstone of vector pest management is surveillance. An IPM program can be initiated for almost any public health pest, even with a limited knowledge of the transmission dynamics, by implementing a monitoring strategy. Surveillance determines potential risk, when and where to treat, and the basis for adapting management interventions to a particular area (Service 1993). Monitoring typically focuses on the incidence of the vector and pathogens. Pathogen surveillance may be in vectors, sentinel hosts, or humans (disease surveillance). The detection of pathogens can be broadly divided into direct and indirect methods (Manson-Bahr and Bell 1987, Duvallet et al. 1999). Direct pathogen surveillance includes any method that isolates the disease agent, in vivo or in vitro, or some characteristic biochemical or structural component of the pathogen (e.g., visual detection, biochemical response to the pathogen, and identification of DNA/RNA sequences or fragmentation patterns). Indirect pathogen surveillance includes methods that rely on an in vivo or in vitro response to the pathogen, including detection of characteristic pathology or antibody response (host serology or various immunoassay methods) (Coyle 1997). Federal, state, and/or local public health agencies in the United States are usually responsible for pathogen or disease surveillance and measuring trends in disease incidence. However, human disease surveillance is seldom an effective tool for managing an outbreak (Teutsch 1994). For example, the response to the WNV outbreak in New York City included distribution of repellents to the public, aerial applications of malathion and sumithrin, and a vast public relations effort to warn and advise residents on how to avoid

pesticide and mosquito exposure. An examination of the 1999 case data and onset dates indicates that the epidemic had already peaked before the majority of these actions were taken (CDC 1999). In contrast, vector control may have reduced the number of human WNV cases in 2000, although it was unable to contain the spread of the virus (CDC 2001b)

Most mosquito abatement districts (MADs) in the United States focus on monitoring vector species (MADs generally focus on mosquito management; however, their mandate frequently includes other nuisance and vector arthropods and vertebrate pests). The goal of vector management is to implement control techniques to reduce pest abundance below the levels necessary for the transition from enzootic transmission to epizootic or epidemic transmission. Unfortunately, due to the ecological and biological complexities of pathogen transmission, predictive models are few (Monath 1988, CDC 1993). Thus, most MADs attempt to prophylactically reduce vector populations without knowing whether they are disrupting a pathogen transmission cycle. Typically, they rely on seroconversion of sentinel animal hosts (such as chickens for St. Louis encephalitis virus) or public health bulletins of human cases before they implement emergency control measures, such as ultralow volume spraying for adult mosquitoes. For several vector-borne diseases, the ability to detect pathogens in low concentration, as well as identify vector and pathogen species and species subgroups by molecular techniques has revolutionized epidemiological studies and provided vector management groups with an early warning system (Howe et al. 1992, Crabtree et al. 1995, DeBrunner-Vossbrinck et al. 1996).

Despite the similarities of vector management to crop pest management, there are significant differences. For example, a pathogen transmission cycle may include enzootic and epizootic cycles, involving multiple hosts, reservoirs, and vectors that exhibit considerable habitat, seasonal, and/or bionomic variation (Harwood and James 1979). Transmission cycles may be unknown, not apparent, or difficult to detect and predict. In general, the number of confirmed cases of a vector-borne disease underestimate the number of people infected with a pathogen. Furthermore, action thresholds in vector management (the level of tolerance of disease transmission before a management intervention is taken) are lower than economic thresholds for crop pests (the level of damage tolerance before an intervention is taken). For these reasons, public health-oriented management programs rely on long-term and short-term prophylactic treatments to reduce vector populations and eliminate breeding sites before pathogen transmission has been detected, unlike crop pest management (Metcalf and Metcalf 1993, Mulla 1994, WHO 1995). This approach allows the use of natural enemies, source reduction, sanitation and sewage management, vegetation and water-flow (salt and freshwater) management, growth regulators, microbial control agents, and relatively host-specific insecticides (Dale et al. 1998, Carlson et al. 1999, Russell 1999). Prophylactic interventions are generally habitat- and vector-specific, whereas emergency interventions tend to rely on insecticides dispensed over broader areas that affect a greater number of nontarget organisms. Insecticides will probably always be an important component of vector management programs because of their ease of application, efficacy, and rapid action. The benefit/cost ratio for pest control is from $3 to $5 per $1 invested in agriculture and, for vector control, is estimated at approximately $2.7 per $1 invested (Metcalf 1998). Personal protection includes repellents, antibacterials, vaccines (few are available for arthropod-borne diseases), and physical avoidance of the vector.

IPM for public health pests is an areawide problem, involving public and private lands in urban, agricultural, and natural habitats. Therefore, vector abatement programs often require the cooperation of several agencies and/or quasi-legal groups at the local, regional, and national levels. Vector management also deals with several potentially volatile topics, such human and animal health, pesticide application in urban environments, insecticide impact on feral and domestic wildlife, and modification of human behavior to avoid exposure; therefore, it typically requires the cooperation of the public and various governmental bodies.

In the United States, the mosquito abatement districts are area-specific, taxing bodies that focus on monitoring and controlling the vector within a county, suburb, or metropolitan area. Pathogen and/or disease surveillance by local or state public health departments and the Centers for Disease Control and Prevention assist in detection, trend analysis, standardization of techniques, and training in vector and disease management. Primary caregivers generally control prophylactic and/or therapeutic drugs. The cost of vector management may exceed the capabilities of local areas; thus, requiring a governmental presence.

## CASE STUDY – WEST NILE VIRUS

As of mid-October 2001, WNV has been detected in 27 states and Washington, DC. Although the number of clinical cases (43 people) in 2001 was low, despite its significant geographical expansion, WNV caused more than 200 cases in horses and more than 3,060 dead crows and 1,191 other birds. During this period, avian reservoir hosts showing little or no symptoms of WNV probably numbered in the millions.

The mosquito abatement approach to WNV largely relied on the assumption that the transmission dynamics WNV are similar to those previously experienced with SLEV. However, there is a growing body of evidence that suggests transmission models for SLEV may not be adequate for understanding the complexities of WNV. The obvious difference is the large number of mosquitoes found positive with WNV, 29 species in North America and the large number of bird species that have been killed due to viral infection, 111 in North America. Moreover, the hallmarks of the WNV epidemic that differ from prior SLEV epidemics are 1) extremely rapid range expansion; 2) high mortality in corvids and raptors; 3) extremely high seroprevalence in many game and nongame bird species; 4) possibility of bird-to-bird transmission and infection of predaceous birds by infected prey (neither have been demonstrated in the field); 5) overwintering in northern latitudes and reemergence early in the season at multiple sites under a variety of meteorological conditions; 6) poor stationary sentinel performance, and 7) a transmission cycle involving horses and other mammals, which suggests the involvement of a number of mosquito vectors other than *Cx. pipiens*, *Cx. restuans*, and *Cx. Salinarius*, which are considered the mosquitoes responsible for SLEV transmission in the United States. Because these observations would not be considered typical for SLEV transmission and, if they hold true for the Midwest, they significantly impact mosquito abatement and arbovirus surveillance activities. Some laboratory tests suggest transmission by transovarial and/or transstadial means are more common with WNV than SLEV. Although very general weather models have been used for predicting SLEV epidemics, these seem ineffective for predicting WNV transmission. Our lack of knowledge about specific aspects of WNV transmission dynamics represents a significant impediment to effective management through mosquito abatement.

One of the bright spots regarding the WNV epidemic in Illinois was found in areas where active IPM-oriented mosquito control programs are found. The Northwest Mosquito Abatement District (NWMAD) in north western Cook County had significantly fewer human cases than in areas where organized mosquito abatement was not present. The NWMAD had to deal with WNV in 2001 and was prepared to take the preventative and surveillance measures to minimize transmission in 2002. Active larval control of *Culex* species coupled with aggressive management of floodwater mosquito species played a significant role in keeping these populations suppressed. An active WNV surveillance using the

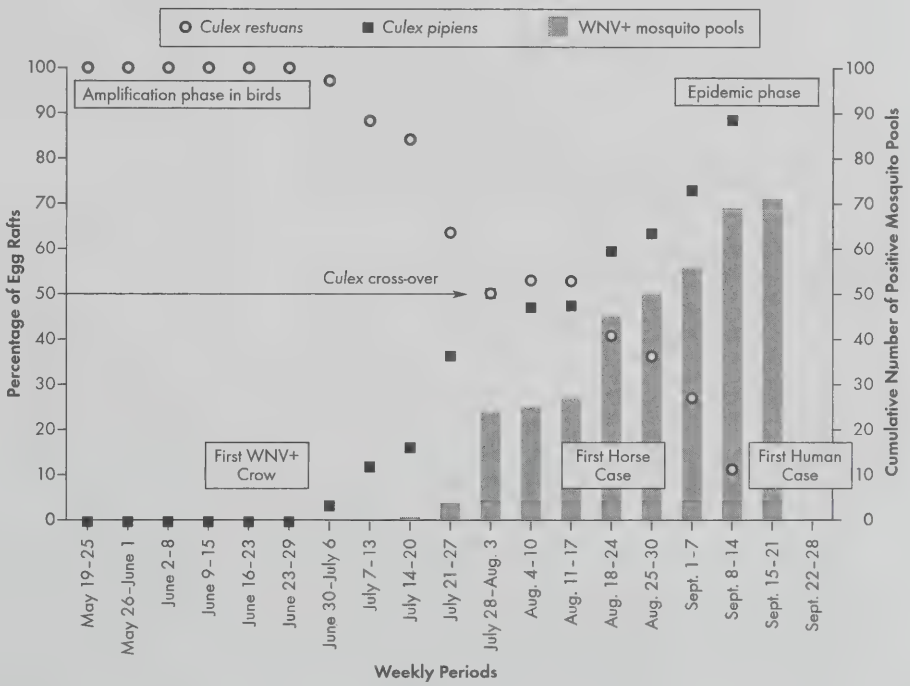



**Figure 2 ■ Relative *Culex* species abundance and transmission dynamics of West Nile Virus in Champaign, Urbana, and Savoy in 2002.**

VecTest followed with *TaqMan* RT-PCR became standard operational method used to prioritize and guide mosquito control operations. Although the Vectest is not as sensitive to detect WNV as *Taqman* RT-PCR it was used to determine areas of viral activity followed by stepped-up larval control operations. It was also used in making the decision to use adult treatment when a area was well defined, the weather conditions were conducive to aerial application, and where additional larval control could not reduce increasing and the WNV-positive mosquito population. This IPM basic strategy played a large role in minimizing human and other animal cases within the geographic boundaries of the NWMAD.

Similarly, the Champaign/Urbana/University/Savoy Vector Control Program (CUUSVCP), a ongoing targeted mosquito control operated through the INHS, Medical Entomology Lab successfully kept human WNV to a single case during 2002. The CUUSVCP vector control program, which has been in existence since 1975, was able to use current and historical field data on mosquito larval habitats to direct control operations. Beginning in May 2002, inspection and control of storm sewer catch basins and *Culex* larval breeding sites was initiated. Surveillance for WNV-infected mosquitoes was done at sampling stations located at different locales within the boundaries of the Program. Adult mosquitoes were sampled using $CO_2$-charged CDC miniature light traps; gravid traps, which collect egg-laying female mosquitoes; and oviposition traps, which collect *Culex* species egg rafts. Figure 2 illustrates the *Culex* population and associated WNV-positive mosquito pools over the summer 2002. It is postulated that *Cx. restuans*, an early-spring mosquito and a bird-specific feeder, amplified the virus in the bird population beginning in early May when the virus was first identified in a dead American crow. The dead crow was found at Hessel Park in southwestern Champaign adjacent to Parkland College. Adult samples were collected in the area, which tested positive, while at the same time mosquito larval control within the area was increased to locate new larval sites as well as to ensure that previously know larval sites were under management. The location of dead crows was a valuable source of surveillance information and the program used this as a method to initial target risk areas for increased surveillance and control. By using a proactive surveillance system with dead birds (American crows, blue jays, corvids, and raptors), detecting WNV-positive mosquito species, and the location of larval habitats throughout the area for summer 2002, the program was able to minimize the impact of WNV through mosquito management to the citizens of Champaign, Urbana, Savoy, and the university community.

## CONCLUSIONS

West Nile virus arrived in North America in 1999 and in three summers has moved coast to coast in the United States and south into Central America. Although the number of human cases in areas where the virus first appeared are fewer, there still is transmission to both humans and horses. Transmission of this virus to bird populations continues throughout the United States regardless of the time the virus made its first appearance. This information coupled with epidemiological data from the middle east, where WNV has been endemic for years, tells us that this virus may be a yearly problem where the severity of transmission can vary widely from year to year. The final impact on wildlife especially wild bird populations is still unknown. It is important to continue sampling wild bird populations to establish how extensive the WNV antibody prevalence rate is by species. This information will give us critical data on their potential survival, especially important for endangered and threatened species.

The greatest problem associated with the management of WNV is the unknown. We must learn more about the transmission cycle and pinpoint those mosquitoes, birds, and animals that play significant roles in the maintenance and actual transmission of the virus. This task is major, because the virus has been found in 29 mosquito species and in more than 111 birds and an increasing number of domestic and wild mammals. In terms of mosquito control the IPM concept of targeting mosquitoes when they are the most concentrated, immobile, and accessible must be our guiding principal. Managing the mosquito larvae is the only way to significantly reduce their populations. Adult control should only be used as a last chance effort and only under specific environmental and biological conditions. By having IPM vector control program as new information becomes available it can than be quickly applied to mosquito control operations. It is also necessary to develop and implement greater cooperation between mosquito abatement districts, municipal agencies, city and county public health departments, conservation districts, and the public to the threat caused by WNV and any other invading exotic that affects the people,

the economy, and the natural resources of Illinois. This challenge will be addressed by state and local government before the mosquito WNV season beginning in 2003.

## REFERENCES


Baqar S., Hayes, C. G, Murphy, J. R, and Watts, D. M. 1993. Vertical transmission of West Nile virus by *Culex* and *Aedes* species mosquitoes. American Journal Tropical Medicine Hygiene 48: 757–762.

Blitvich, B. J., N. L. Marlenee, R. A. Hall, C. H. Calisher, R. A. Bowen, J. T. Roehrig, N. Komar, S. A. Langevin, and B. J. Beaty. 2002. Epitope-blocking enzyme-linked immunosorbent assays for the detection of serum antibodies to West Nile virus in multiple avian species. Journal of Clinical Microbiology. In review.

Carlson, D. B., P. D. O'Bryan, and J. R. Rey. 1999. Florida's salt-marsh management issues: 1991–98. [Article] Journal American Mosquito Control Association. 15: 186–193.

Centers for Disease Control (CDC). 1993. Guidelines for arbovirus surveillance in the United States, Fort Collins, Colorado: U.S. Department of Health and Human Services, CDC.

Centers for Disease Control (CDC). 1999. Outbreak of West Nile-like viral encephalitis- New York, 1999. Morbidity Mortality Weekly Report 48: 845–849.

Centers for Disease Control (CDC). 2001b. Human West Nile Virus Surveillance-Connecticut, New Jersey, and New York, 2000. Morbidity Mortality Weekly Report 50: 265–268.

Coyle, P. K. 1997. *Borrelia burgdorderi* infection: clinical diagnostic techniques. Immunological Investigations 26: 117–128.

Crabtree, M. B, H. M. Savage, and B. R. Miller. 1995. Development of a species-diagnostic polymerase chain reaction assay for the identification of *Culex* vectors of St. Louis encephalitis virus based on interspecies sequence variation in ribosomal DNA spacers. American Journal Tropical Medicine Hygiene 53: 105–109.

Dale, P.E.R., S. A. Ritchie, B. M. Territo, C. D. Morris, A. Muhar, and B. H. Kay. 1998. An overview of remote sensing and GIS for surveillance of mosquito vector habitats and risk assessment. Journal Vector Ecology 23: 54–61.

DeBrenner-Vossbrinck, B. A, C. R. Vossbrinck, M. H. Vodkin, and R. J. Novak. 1996. Analysis of the ribosomal DNA internal transcribed spacer region of *Culex restuans* and mosquitoes in the *Culex pipiens* complex. Journal American Mosquito Control Association 12: 477–482.

Dent, D R (1995) Integrated Pest Management. Chapman & Hall, London.

Duvallet, G., S. de la Rocque, J. M. Reifenberg, P. Solano , T. Lefrancois, J. F. Michel, Z. Bengaly, I. Sidibe, D. Cuisance, and G. Cuny. 1999. Review on the molecular tools for the understanding of the epidemiology of animal trypanosomosis in West Africa. Memorias do Instituto Oswaldo Cruz. 94: 245–248.

Harwood, R. F., and M. T. James. 1979. Entomology in Human and Animal Health, seventh edition. Macmillan Publishing Co., Inc., New York.

Howe, D. K., M. H. Vodkin, R. J. Novak, C. J. Mitchell, and G. L. McLaughlin. 1992. Detection of the St. Louis encephalitis virus in mosquitoes by use of the polymerase chain reaction. Journal American Mosquito Control Association 8: 333–335.

Kogan, M. 1998. Integrated pest management – historical perspectives and contemporary developments. Annual Review of Entomology 43: 243–270.

Lichtensteiger, C. A., K. Heinz-Taheny, T. S. Osborne, R. J. Novak, B. A. Lewis, and M. L. Firth. 2002. Fatal West Nile virus encephalitis and myocarditis in two canids (wolf and dog). Emerging Infectious Diseases. In review.

Manson-Bahr, P.E.C. and D. R. Bell. 1987. Manson's Tropical Diseases, 19th edition. Balliere Tindall, Philadelphia, PA.

Metcalf, R. L., and R. A. Metcalf. 1993. Destructive and Useful Insects: Their Habits and Control, 5th ed. McGraw-Hill Book Company, New York.

Metcalf, R. L. and R. J. Novak. 1994. Pest management strategies for insects affecting humans and domestic animals. In: Introduction to Insect Pest Management (Metcalf R. L. and R. Luckman eds) pp. 587-628, John Wiley & Sons, New York.

Metcalf, R. L. 1998. Pesticides. In: Encyclopedia of Environmental Science and Engineering, 4th ed. (J. R. Pfafflin and E. N. Ziegler eds), pp. 1037-1051, Gordon and Breach Science Publishers, The Netherlands.

Miller, B. R., Nasci, R. S., Godsey, M. S., Savage, H. M., Lutwama, J. J., Lanciotti, R. S., and Peters, C. J. 2000. First field evidence for natural vertical transmission of West Nile virus in *Culex univittatus* complex mosquitoes from Rift Valley Province, Kenya. American Journal Tropical Medicine Hygiene 62: 240–246.

Mishra, A. C. and D. T. Mourya. 2001. Transovarial transmission of West Nile virus in *Culex vishnui* mosquito. Indian Journal Medical Research 114: 212–214.

Monath, T. P., ed. 1988. The Arboviruses: Epidemiology and Ecology, Vols. 1–6. CRC Press, Boca Raton, FL.

Mulla, M. S. 1994. Mosquito control then, now, and in the future. Journal American Mosquito Control Association 10: 574–584.

Russell, R. C. 1999. Constructed wetlands and mosquitoes: health hazards and management options - an Australian perspective. Ecological Engineering 12: 107–124.

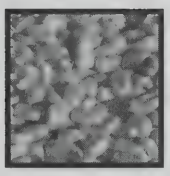
Service, M. W. 1993. Mosquito Ecology: Field Sampling Methods, 2nd ed. Elsevier Applied Science. New York.

Teutsch, S. M. 1994. Considerations in planning a surveillance system. In: Principles and Practice of Public Health Surveillance (Teutsch, S. M., R. E. Churchill eds), pp. 18–30, Oxford University Press, New York.

Turell, M. J. O'Guinn, M. and Oliver, J. 2000. Potential for New York mosquitoes to transmit West Nile virus. American Journal Tropical Medicine Hygiene 62: 413–414.

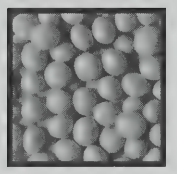
Turell, M. J., O'Guinn, M. L., Dohm, D. J., and Jones, J. W. 2001. Vector competence of North American mosquitoes (Diptera : Culicidae) for West Nile virus. Journal Medical Entomology 38: 130–134.

World Health Organization (WHO). 1995. Vector Control for Malaria and Other Mosquito-Borne Diseases Report of a WHO Study Group Technical Report Series, No. 857.



# GATHERING STORM OR DISSIPATING THREAT? STATUS, PROGNOSIS, AND MANAGEMENT OF THE SOYBEAN APHID

**Ken Ostlie**



# CONFLICT . . . AN OPPORTUNITY FOR DEVELOPMENT

**Ben Mueller and Anne Heinze Silvis**

Believe it or not, conflict is an opportunity for development. The opportunity lies in managing difficult situations to create some good from the energy, interest, and emotion that people bring to the conflict. This workshop will help you better understand the conflict cycle, provide some strategies for managing conflict, and give you a chance to practice analyzing conflict and working to resolve it. It is unrealistic to expect that our lives will be free of conflict, but it is realistic to learn how to manage conflict to minimize the negative consequences and maximize the positive outcomes.

Learning objectives

- Increase your knowledge of theories that provide a framework for understanding conflict.
- Learn to use the "conflict cycle" as a diagnostic tool.
- Become familiar with several techniques and approaches to manage and resolve conflicts.
- Practice behaviors useful in mitigating or managing conflict.

## RESOURCES

### Books

Bacow, Lawrence and Michael Wheeler. 1984. *Environmental Dispute Resolution*. New York: Plenum Publishing Co.

Baruch Bush, Robert A., and Joseph P. Folger. 1994. *The Promise of Mediation: Responding to Conflict Through Empowerment and Recognition*. San Francisco: Jossey-Bass Inc., Publishers.

Bennis, Warren. 1999. *Managing People is Like Herding Cats*. Provo, UT: Executive Excellence Publishing.

Bingham, Gail. 1986. *Resolving Environmental Disputes*. Washington, DC: Conservation Foundation.

Blackburn, J. Walton, and Willa Marie Bruce. 1995. *Mediating Environmental Conflicts: Theory and Practice*. Westport, CT: Quorum Books.

Bolton, Robert. 1979. *People Skills*, 3rd ed. Englewood Cliffs, NJ: Prentice Hall, Inc.

Bramson, Robert M. 1981. *Coping with Difficult People*. Garden City: Anchor Press; New York: Doubleday.

Bush, R.A.B. and J.P. Folger. 1994. *The Promise of Mediation: Responding to conflict through empowerment and recognition*. San Francisco: Jossey-Bass Inc., Publishers.

Carpenter, Susan L. and W.J.D. Kennedy. 1988. *Managing Public Disputes: A Practical Guide to Handling Conflict and Reaching Agreements*. San Francisco: Jossey-Bass Inc., Publishers.

—. 1990. *Solving Problems by Consensus*. Washington, DC: Program for Community Problem Solving.

Costantino, Cathy A. and Christina Sickles Merchant. 1996. *Designing Conflict Management Systems: A Guide to Creating Productive and Healthy Organizations*. San Francisco: Jossey-Bass Inc., Publishers.

Creighton, James L. 1992. *Involving Citizens in Community Decision Making: A Guidebook*. Washington, DC: Program for Community Problem Solving.

Crowe, Sandra A. 1999. *Since Strangling Isn't an Option…: Dealing with Difficult People – Common Problems and Uncommon Solutions*. New York: The Berkley Publishing Group.

Doyle, Michael and David Straus. 1982. *How to Make Meetings Work*. New York: Jove Books.

Dukes, Franklin E. 1996. *Resolving Public Conflict: Transforming Community Through Governance*. Manchester: Manchester University Press.

—, Marina A. Piscolish, and John B. Stephens. 2000. *Reaching for Higher Ground in Conflict Resolution: Tools for Powerful Groups and Communities*. San Francisco: Jossey-Bass Inc., Publishers.

Fisher, Roger and William Ury. 1991. *Getting to Yes: Negotiating Agreement Without Giving In*, 2nd ed. (Bruce Patton ed.), New York: Penguin Books.

Gray, Barbara. 1989. *Collaborating: Finding Common Ground for Multiparty Problems*. San Francisco: Jossey-Bass Inc., Publishers.

Herman, Margaret S. 1987. *Mediation in a Regional Setting: Facilitating Dispute Resolution and Decision Making*. Washington, DC: National Association of Regional Councils.

—, ed. 1994. *Resolving Conflict: Strategies for Local Government*. Washington, DC: International City / County Management Association.

Kaner, Sam. 1996. *Facilitator's Guide to Participatory Decision-Making*. Philadelphia: New Society Publishers.

Lake, Robert W., ed. 1987. *Resolving Locational Conflict*. New Brunswick, NJ: Center for Urban Policy Research, Rutgers University.

Lang, Michael D. and Alison Taylor. 2000. *The Making of a Mediator: Developing Artistry in Practice*. San Francisco: Jossey-Bass Inc., Publishers.

Lincoln, William F., *et al*. 1986 *The Course in Collaborative Negotiations*. Tacoma, WA: National Center Associates.

Lundin, William and Kathleen Lundin. 1995. *Working with Difficult People*. New York: American Management Association.

Madigan, Denise, Gerald McMahon, Lawrence Susskind, and Stephanie Rolley. 1990. *New Approaches for Resolving Local Public Disputes*. Washington, DC: National Institute for Dispute Resolution.

Markham, Ursula. 1993. *How to Deal with Difficult People*. New Delhi, India: Harper Collins Publishers.

Mayer, Bernard. 2000. *The Dynamics of Conflict Resolution: A Practitioner's Guide*. San Francisco: Jossey-Bass Inc., Publishers.

Moore, Christopher W. 1996. *The Mediation Process: Practical Strategies for Resolving Conflict*, 2nd ed. Jossey-Bass Inc., Publishers.

Ozawa, Connie P. 1991. *Recasting Science: Consensus Procedures in Public Policy Making*. Boulder, CO: Westview Press.

Pike, Bob and Dave Arch. 1997. *Dealing with Difficult Participants: 127 Practical Strategies for Minimizing Resistance and Maximizing Results in Your Presentations*. San Francisco: Jossey-Bass Inc., Publishers; Minneapolis: Creative Training Techniques Press.

Rothman, Jay. 1997. *Resolving Identity-Based Conflict in Nations, Organizations, and Communities*. San Francisco: Jossey-Bass Inc., Publishers.

Sacarto, Douglas M. 1985. *Economic Development Conflicts: Model Programs for Dispute Resolution*. Denver, CO: National Conference of State Legislatures.

Sandole, Dennis and Hugo van der Merwe, eds. 1993. *Conflict Resolution Theory and Practice: Integration and Application*. Manchester, UK: Manchester University Press.

Slaikeu, Karl A. 1996. *When Push Comes to Shove: A Practical Guide to Mediating Disputes*. San Francisco, CO: Jossey-Bass Inc., Publishers.

Solomon, Muriel. 1990. *Working with Difficult People*. Englewood Cliffs, NJ: Prentice Hall.

Susskind, Lawrence and Jeffrey Cruishank. 1987. *Breaking the Impasse: Consensual Approaches to Resolving Public Disputes*. New York: Basic Books.

Toropov, Brandon. 1997. *The Complete Idiot's Guide to Getting Along with Difficult People*. New York: Alpha Books.

Ury, William L., Jeanee M. Brett, and Stephen B. Goldberg. 1989. *Getting Disputes Resolved: Designing Systems to Cut the Costs of Conflict*. San Francisco: Jossey-Bass Inc., Publishers.

Weisinger, Hendrie. 1998. *Emotional Intelligence at Work: The Untapped Edge for Success*. San Francisco: Jossey-Bass Inc., Publishers.

Weiss, Donald H. 1987. *How to Deal with Difficult People*. New York: American Management Association.

Wondolleck, Julia M. 1988. *Public Lands Conflict and Resolution: Managing National Forest Disputes*. New York: Plenum Publishing Co.

### Newsletters and Journals

*Alternatives*
CPR Institute for Dispute Resolution
366 Madison Avenue
New York, NY 10017-3122
(212) 949-6490

The CPR Institute for Dispute Resolution is a nonprofit initiative of global corporations, law firms, and law teachers developing new uses of alternative dispute resolution (ADR) for business and public disputes. *Alternatives* is CPR's news-monthly on new uses of ADR. Online information is at www.cpradr.org

*Consensus*
131 Mount Auburn St.
Cambridge, MA 02138
(617) 492-1414

Part of Harvard University's Program on Negotiation. Quarterly newsletter with helpful information on theory and practice.

*Dispute Resolution Forum*
National Institute for Dispute Resolution
1901 L Street, NW
Suite 600
Washington, DC 20036
(202) 466-4764

This organization publishes a free catalog that highlights new resources, including books, articles, videos, and conferences.

*Mediation Quarterly*
Jossey-Bass Inc., Publishers
350 Sansome Street, Fifth Floor
San Francisco, CA 94104
(800) 956-7739

A leading peer-reviewed journal devoted to covering the latest developments in theory and the practice of mediation. Online information at www.jbp.com/

*Negotiation Journal: On the Process of Dispute Settlement*
Jacob Cherian
Customer Service
Plenum Press Journals
233 Spring Street
New York, NY 10013
(212) 620-8468

This is often mentioned as the premier journal in the dispute resolution field. It is published quarterly in cooperation with the Harvard Program on Negotiation. Each issue includes case studies, developments in the theory of dispute resolution, book reviews, and educational innovations.

*Resolve*
World Wildlife Fund/The Conservation Foundation
1250 Twenty-Fourth St. NW
Washington, DC 20037-1175
(800) 225-5993

*The Journal of Extension* occasionally includes an article that addresses conflict or public issues resolution. The August 2001 issue features an article that describes a process for public issues education. The issue is included in the archive at http://www.joe.org/joe/2001august/a2.html

### On the Web

www.communitydevelopment.uiuc.edu

Self-Directed Learning

- http://www.pasturemanagement.com/peoplephases.htm
- http://www.communitybuilders.nsw.gov.au/ext/articles/techniques/conflict.html
- http://www.nsba.org/sbot/toolkit/Conflict.html
- http://www.ianr.unl.edu/pubs/family/heg181.htm

Resources and Publications

- http://www.adr.org/(American Arbitration Association provides a publication entitled, Resolving Professional Accounting and Related Services Disputes – A Guide to Alternative Dispute Resolution.)
- http://www.state.oh.us/cdr/resources.htm (reports and materials for working with youth and the school community.)

- http://www.mediators.org/
- http://www.ncpc.org/1safe5dc.htm (from Allstate Foundation)
- http://www.ctic.purdue.edu/KYW/Brochures/ManageConflict.html (watershed management)
- http://www.nsba.org/sbot/toolkit/index.html
- http://www.ianr.unl.edu/pubs/family/heg181.htm
- http://studentlife.tamu.edu/scrs/sms/sms_conflict_tips.htm
- http://arts.endow.gov/pub/Lessons/Lessons/ANGELO.html
- http://www.campuslife.utoronto.ca/services/police/conflict.html
- http://www.library.wisc.edu/libraries/Steenbock/services/commuext.htm

Projects and Case Studies

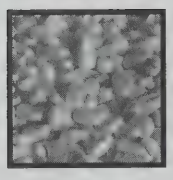
- http://www.state.oh.us/cdr/resources.htm
- http://www.policyconsensus.org/

Curriculum

- Turning Lemons into Lemonade, www.ext.msstate.edu/srdc/publications/lemons/221.htm
- http://www.coe.ufl.edu/CRPM/CRPMhome.html

Classes

- http://www.qvctc.commnet.edu/classes/ssci121/Index.htm



# ECONOMICS OF SITE-SPECIFIC MANAGEMENT

**Jess Lowenberg-DeBoer**

## INTRODUCTION

Persistent questions about profitability have held back adoption of precision agriculture technology. Grain yield monitors, global positioning system (GPS) guidance, and variable rate application (VRA) of fertilizer on some higher value crops are moving toward becoming standard practice, whereas use of VRA for pesticides and seeding has lagged. This presentation focuses on three questions: 1) Who is using precision agriculture technology? 2) What aspects of precision agriculture are most profitable? and 3) What are the problems encountered in estimating the profitability of precision agriculture?

## ADOPTION

Yield monitoring has been the "killer application" of precision agriculture, almost every where in the world. GPS guidance (lightbar) is the second most common precision agriculture tool in many places. VRA of fertilizer has been growing slowly.

Approximately 34% of U.S. corn acreage was harvested with a combine equipped with a yield monitor in 2001, but only about one-third of those combines also had GPS. Hence, only about 11% of U.S. corn acreage could have been yield mapped in 2001.

Some 44% of ground-based agricultural custom application equipment in the United States used GPS guidance in 2002. Numerical estimates are not available, but informal reports indicate that GPS guidance has experienced similar growth among producers.

Use of VRA fertilizer has grown more slowly than yield monitoring or GPS guidance. About 11% of U.S. corn acreage was managed with VRA fertilizer in 2000, compared with 6% for soybean, 3% for wheat, and 4% for cotton. Some 20% of U.S. corn acreage has been intensively soil tested at some time in the past 15 years.

There has been widespread experimentation with computer controlled VRA for pesticides and seeding, but relatively little adoption. VRA pesticides were used on 3% of corn acreage and 1% of soybean acreage in 2000. One of the key problems is the cost of developing an accurate map of pest locations. Computer controlled VRA pesticide is most common for perennial weeds, because they tend to stay in the same area from year to year and are thus easy to map. Annual weeds and insects are mobile. Weed seeds are moved by water, wind, animals, and harvesting operations. Insects walk, crawl, or fly. Low-cost, hand-held GPS units may help reduce the cost of pest scouting and enable wider use of VRA pesticides.

Remote sensing from satellites or with aerial photograph also promises to help reduce the cost of pest scouting, but marketing and technical problems have limited availability of remote images. Approximately 5% of corn acreage and 4% of soybean acreage in the United States were managed with the help of remote images in 2000.

VRA seeding is an old idea. There were manually operated systems for changing plant populations 30 years ago. Retrofitting existing equipment for VRA seeding is relatively inexpensive. However, studies have shown that unless there is a very wide range of

optimal plant populations, VRA seeding is not very profitable. Two studies in corn show that VRA seeding pays only if there are substantial areas of the farm that have under 100 bu/acre yield potential. In 2000, approximately 3% of corn acreage and 2% of soybean acreage in the United States was managed using VRA seeding.

## PROFITABILITY

Most economic studies on precision agriculture have been done on VRA of fertilizer because it was the first precision agriculture technology that was commercially available. These studies show that VRA is more likely to be profitable on higher value crops, such as sugar beets, than on bulk commodities such as corn and soybean. Some evidence indicates that integrated precision agricultural systems are more profitable than stand-alone technologies because in integrated systems equipment, information, and human capital costs can be spread over several inputs and because interactions between managed inputs can be fine-tuned. Systems that use site-specific recommendations based on local trials are also more likely to be profitable than those that use statewide or regional recommendations.

The whole-farm and off-farm benefits of precision agriculture are largely unstudied, but anecdotal information indicates that use of precision tools for logistics planning, monitoring crops and employees, marketing differentiated products, risk management, farmland purchase and rental, and other off-field uses may be much more profitable than field-level use.

With the increasing pace of technology change in agriculture, one of the key uses of yield monitoring and other sensor technology is to facilitate more on-farm testing. Experimental designs are being developed that allow useful information to be collected with a minimum of interference with regular cropping operations. Either/or tests between pesticide alternatives, tillage types, or genetics are particularly easy to implement.

## BUDGETING ISSUES

Precision agriculture technology can be analyzed like any other new technology. Information is an input in the production process, like seed, fertilizer, chemicals, or fuel. Information has value if it leads to better decisions. If information is used over multiple years it should be treated as a durable input. In most cases, it has been more difficult to estimate the benefits of precision agriculture than the costs. For field-level technologies, on-farm trial design and analysis needs to recognize the spatial variability of the site. Estimation of whole-farm benefits requires whole-farm information.

## CONCLUSIONS

Precision agriculture technology is being used in mechanized agriculture worldwide. Yield monitoring is the most common first step in precision agriculture. Use of VRA fertilizer has been increasing slowly, but use of VRA pesticides has lagged. One key problem with VRA pesticide use is the cost of developing pest maps. Low-cost, hand-held GPS units and remote sensing may help lower those costs. The economics of precision agriculture are site-specific. Profitability is likely to vary from farm to farm because of soils, previous management, microclimates, and other factors.

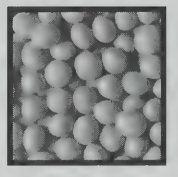
## REFERENCES


Daberkow, S., J. Fernandez-Cornejo, and M. Padgitt. 2002. Precision Agriculture Technology Diffusion: Current Status and Future Prospects. Paper presented at the 6th International Precision Farming Conference, Minneapolis, MN, July, 2002.

Lowenberg-DeBoer, J., and K. Erickson [eds]. 2000. *Precision Farming Profitability*, Agricultural Research Programs, Purdue University, West Lafayette, IN.

Swinton, S.M., and J. Lowenberg-DeBoer. 1998. Evaluating the profitability of site specific farming. *Journal of Production Agriculture* 11: 439–446.

Whipker, Linda, and Jay Akridge. 2002. Precision Agricultural Services: Dealership Survey Results. Staff Paper No. 02-02, Center for Food and Agricultural Business, Purdue University, West Lafayette, IN, June, 2002. (http://mollisol.agry.purdue.edu/SSMC/ click on publications)



# BIOLOGY AND CONTROL OF SELECTED PROBLEM WEEDS

**William S. Curran**

A number of problem weeds continue to limit row crop production. Shifts or changes in the abundance and types of weeds within agricultural systems are commonplace. These shifts can occur for a number of reasons and may result from cultural, mechanical, or chemical weed management strategies. The right combination of weeds and relying too heavily on any one practice is often the most common cause. The adoption of Roundup Ready soybean has helped manage numerous weeds, but several problem annuals and perennials still demand our attention. This presentation focuses on those weeds that continue to be challenging and draws attention to specific management opportunities. Table 1 lists control options and brief descriptions of these troublesome weed species.

## ANNUAL BROADLEAVES

Burcucumber (*Sicyos angulatus*) is becoming a serious weed problem in agronomic crops throughout the northeastern United States. Originally found along stream banks and other damp, shady areas, burcucumber has invaded river bottom and upland fields. Control of burcucumber proves to be a challenge because its germination and growth habits are not fully understood. Burcucumber is a summer annual dicot with stems that are vine-like, branched, and grow to lengths of several meters. Burcucumber seed germinates from mid-May through September. Because burcucumber germinates throughout the season, it is difficult to control with herbicides that lack residual activity. Unfortunately, few soil residual herbicides available for use in corn or soybean provide effective control of burcucumber.

Glyphosate-resistant horseweed (marestail) (*Conyza canadensis*) is classified as a winter or summer annual and has typically been a problem weed in no-till crop production. Horseweed is similar to the fleabanes in appearance and is often one of the first species to invade abandoned fields. The leaves on immature plants form a basal rosette that eventually elongates and bolts, producing a dense panicle-like flowering structure. Numerous small flowers make up the floral structure and each flower produces numerous seed or achenes that are wind dispersed. Glyphosate-resistant horseweed has been identified in several areas of the Unites States and seems to be increasing in prevalence. Thus far, most of the problem areas use no-till and Roundup Ready crops. In no-till, alternative burndown strategies that rely on products other than glyphosate are necessary for control of glyphosate-resistant horseweed. Optimum application timing and herbicide mixtures are critical for successful control.

Triazine-resistant (TR) common lambsquarters (*Chenopodium album*) drives weed control in corn in the northeastern United States. In a recent survey, 80% of livestock farmers in Pennsylvania had TR common lambsquarters on their farm. Common lambsquarters occurs across tillage systems and continues to thrive in numerous production systems. Common lambsquarters is a rapidly growing summer annual that is able to adapt to many environmental conditions. High seed production and seed longevity ensure the continued presence of seedlings for years after a population is controlled. Like most annuals, the best control method is to prevent infestation and spread by minimizing seed production. Fortunately, a number of effective herbicides are

available for lambsquarters control in corn and soybean.

## ANNUAL GRASSES

Smooth and large crabgrass (*Digitaria* species) are increasingly common annual grasses in northeastern row crops. In corn, acetolactate synthase (ALS)-based postemergence programs may have helped shift fields away from the foxtails to more problems with crabgrass. Crabgrass is very difficult to control postemergence in corn. Crabgrass seeds can germinate from mid-spring to late summer, but often emerge after other summer annual weeds have been controlled. Control of crabgrass requires several years of conscientious adherence to an effective management program. The basic principle is to prevent reinfestation by seed. Several of the preemergence grass herbicides are fairly effective, but may require supplemental control postemergence.

Yellow foxtail (*Setaria glauca*) seems to be increasing in prevalence in many areas of the northeastern Unites States. Originally from Europe, yellow foxtail is found throughout the United States and Canada. Of the three foxtails (yellow, green, and giant), yellow is probably the easiest to identify because of the prominent white hairs near the base of the leaf blade. The rest of the blade is hairless. The seed head has prominent yellow awns that helps distinguish it from both giant and green foxtail. In the northeastern United States, yellow foxtail is escaping control in corn similar to crabgrass, especially in some of the postemergence ALS-based herbicide programs. Yellow foxtail seems to emerge later and for a longer period than the other foxtails. Also, yellow foxtail seed is larger than the other foxtails, which may provide earlier season vigor and reduce the effectiveness of some preemergence herbicides. Like other annual grasses, the basic principle is to prevent reinfestation by seed. Several of the preemergence grass herbicides are fairly effective but may require supplemental control postemergence.

## PERENNIALS

Horsenettle (*Solanum carolinense*) is a member of the nightshade family that reproduces by both vegetative means and through seed production. Horsenettle tolerates many commonly used herbicides in both corn and soybean and in particular has increased in prevalence in Roundup Ready soybean in some areas. Although not considered extremely competitive, severe infestations can rob crop yields and cause harvesting difficulties in soybean. In addition, like many other members of the nightshade family, horsenettle is poisonous to livestock and can be a problem in silage or hay crops. Like most herbaceous perennials, a well-timed effective systemic herbicide in combination cultural and mechanical controls can reduce the incidence of horsenettle.

Mugwort (*Artemisia vulgaris*) is increasing in prevalence both in row and ornamental crop production. Mugwort is a creeping herbaceous perennial that primarily reproduces vegetatively. Mugwort growth begins in late April or early May in Pennsylvania and can attain a height of 4 or 5 feet by midsummer. Mugwort tolerates most systemic herbicides typically used in row crop production. Several products, including glyphosate can effectively reduce aboveground growth, but control of the underground vegetative structures remains difficult. An integrated approach that combines herbicides, tillage, and cultural controls is necessary to suppress mugwort growth and reproduction.

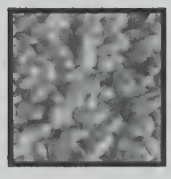
Wirestem muhly (*Muhlenbergia frondosa*) is a perennial grass species that can be a problem in conservation tillage production systems. It is a particular problem in no-till corn and soybean crops but can also be troublesome in orchards, nursery and vegetable crops, and roadsides. Wirestem muhly is a warm-season grass that begins growth in late spring and goes dormant in early fall. The stems of wirestem muhly are branched and stiff, giving the plant a wiry appearance. Wirestem muhly produces abundant viable seed and also has an extensive root system of short, thick, and scaly rhizomes. With few exceptions, corn herbicides are not effective for control of wirestem muhly. However, glyphosate and several of the postgraminicides (acetyl-coenzyme A carboxylase) effectively kill wirestem muhly. A well-timed application of an effective systemic herbicide can reduce wirestem muhly infestations for several years.

Yellow nutsedge (*Cyperus esculentus*) is member of the sedge family that reproduces vegetatively through rhizomes, tubers, and also seed. Vegetative reproduction is considered the most important avenue for the spread of yellow nutsedge within a field. One plant can produce several hundred to several thousand tubers during a single growing season. The chloroactemide herbicides have been widely used over the past 10 years to help manage

this weed in corn and soybean, but with the widespread adoption of Roundup Ready soybean and more frequent use of postemergence strategies in corn, nutsedge populations have increased in some fields. Effective management of yellow nutsedge requires an effective pre- or postherbicide treatment, generally combined with mechanical and cultural controls.

**Table 1 ■ Life cycle, brief description, and control for selected problem weeds.**

| Life Cycle | Weed | *Scientific name* | Description | Control |
|---|---|---|---|---|
| Annual grasses | Crabgrass, large | *Digitaria sanguinalis* | Leaf sheath and blade densely hairy with membranous ligule. Leaf blade short and stout compared with other grasses. | Should be controlled pre in corn. Prowl helps control. In soybeans, most post grass herbicides effective. |
| | Foxtail, Yellow | *Setaria glauca* | Leaf blade with long hairs near base of collar, otherwise hairless. Hair-like ligule. | Later germinating. May need higher rate of pre. Apply most post grass products a little earlier. |
| Perennial grasses | Wirestem muhly | *Muhlenbergia frondosa* | Membranous ligule, smooth flat leaf blade. Close internodes and smooth leaf blades. Scaly rhizomes. | No good pre products available. Accent-containing products suppress in corn. Roundup very good in Roundup Ready corn. Post grass soybean products good. |
| | Nutsedge, yellow | *Cyperus esculentus* | Grass-like, stem is triangular, leaves are smooth, hairless, and deeply keeled. Whole plant is yellowish to pale green. Tubers or nutlets on tips of rhizomes. | Chloroacetamides good for suppression with adequate rainfall. Sutan or Eradicane good. Permit post in corn or Classic or Basagran in soybean. Roundup fair in Roundup Ready crops. |
| Annual broadleaves | Burcucumber | *Sicyos angulatus* | Club-shaped cotlydons and five pointed leaves, alternate. Vining. Seed or burs in clusters. | No good pre products available. Exceed, Spirit, or Beacon in corn, or Classic or Roundupin soybean. |
| | Horseweed (marestail) | *Conyza canadensis* | Similar to fleabane. May act like a winter or summer annual. Typically emerges from fall to early spring. Bolts and produces numerous small seeds that are dispersed by wind. | Problem weed of no-till. Apply burndown herbicides to small rosettes for most effective control. Include 2,4-D in the tank-mix. Glyphosate-resistant horseweed increasing in prevalence. |
| | Lambsquarters, common | *Chenopodium album* | First true leaves are opposite, later alternate. Leaves covered with mealy-like substance. Plants produce numerous viable seed. | Problem in both tilled and no-till. Use effective soil applied program or control postemergence when in seedling stage. More difficult to kill with maturity and after periods of stress (heat/drought). |
| Perennial broadleaves | Horsenettle | *Solanum carolinense* | Leaves are opposite, stem and petioles have spines or thorns. Flowers have white petals and fruits are classified as berries. | Spray in the fall after wheat with Banvel. Include fall tillage where possible. Spray with Roundup + Banvel in Roundup Ready corn, or include suppressive treatment in corn or soybean. |
| | Mugwort | *Artemisia vulgaris* | Clump forming perennial. Aromatic. Young leaves are opposite then alternate with white wooly hairs beneath. Seed production is rare. | Spray in the fall after wheat with Roundup, Banvel,etc. Include fall tillage where possible. Spray with Roundup Ready crops, or include suppressive treatment in corn or soybean. |



# AQUATIC WEED MANAGEMENT

George Czapar

Although plant species are an important part of every aquatic system, excessive weed growth can have a negative effect on ponds, lakes, and drainage ditches and the quality of water for domestic use, wildlife, recreation, and transportation.

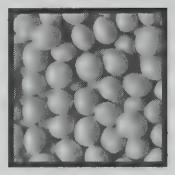
Aquatic plants can be grouped into five general categories: algae, submerged plants, free-floating plants, floating plants that are rooted, and emergent plants along the shoreline or pond margins.

Effective management of aquatic weeds begins with prevention. Aquatic weeds are more common in shallow lakes and ponds that receive nutrient runoff from fields and feedlots, or seepage from septic tanks. Maintaining a sod or grass cover around the pond can help reduce soil erosion and nutrient runoff.

For weeds growing in small patches, mechanical controls such as pulling, dredging, or cutting weeds beneath the water surface can be used. As aquatic weed infestations become more severe, however, mechanical removal is less practical. In some cases, biological control by using grass carp has been helpful in managing aquatic weeds.

If aquatic herbicides are used, product selection and application timing are important considerations. Because no single herbicide controls all types of aquatic plants, correct weed identification is essential. Late spring is usually the best time to apply aquatic herbicides. Weeds are young and actively growing, and the risk of oxygen depletion is less. In late summer, vegetation is usually extensive and herbicide application is not generally recommended. Because dead and decaying plants consume oxygen from the water, fish kills can result.

Finally, most aquatic herbicides have label restrictions or waiting periods on the use of treated water.



# EARTHWORMS AND SOIL MANAGEMENT PRACTICES

**Eileen J. Kladivko**

Earthworms have long been associated with healthy, productive soils. In his 1881 book, entitled "The Formation of Vegetable Mould through the Action of Worms," the great biologist Charles Darwin stated that, "It may be doubted whether there are many other animals which have played so important a part in the history of the world, as have these lowly, organized creatures." Although earthworms are known to be beneficial to soils, their degree of importance in different agricultural systems is poorly understood. This article provides basic information on earthworm ecology, the effects of earthworms on soil properties and processes, and the influence of soil management practices on earthworms. It concludes with a section on how to encourage the buildup of earthworm populations in agricultural fields, as well as some questions that require further study.

## GENERAL ECOLOGY

There are thousands of species of earthworms in the world. Those that live in the soil can generally be grouped into three major behavioral classes: litter-dwellers, shallow soil dwellers, and deep burrowers. The litter-dwelling species live, for example, in the litter layer of a forest and are generally absent from agricultural fields. Typical agricultural fields may have one to five different shallow-dwelling species and perhaps one deep-burrowing species.

The deep burrowers ("nightcrawlers") build large, vertical, permanent burrows that may extend 5 to 6 feet or more in depth. They pull plant residues down into the opening of their burrow, where the residues soften and can be eaten at a later time. Nightcrawlers construct middens over the entrance of their burrows. Middens are a mixture of plant residues and castings (worm feces) and probably serve as protection as well as a food reserve. Because nightcrawlers require residues at the surface to pull down into their burrows, nightcrawlers are not usually found in fields that routinely leave no surface residue cover (i.e., moldboard-plowed). The species of nightcrawler in the north central region of the United States is *Lumbricus terrestris*. The length of adult nightcrawlers is usually 4 to 8 inches or longer.

The shallow-dwelling worms (known as redworms, grayworms, fishworms, and many other names) are comprised of many species that live primarily in the top 12 inches of soil. Adult length is usually 3 to 5 inches. They do not build permanent burrows, but instead they randomly burrow throughout the topsoil, ingesting residues and mineral soil as they go. Because they do not require residues at the surface specifically, we do not expect them to be as sensitive to residue management as are the nightcrawlers. However, they are affected by the amount of surface mulch because of the impact on soil temperature and moisture extremes, which is discussed in more detail in the section on tillage.

Earthworms are seasonal in their activity. The shallow dwellers are active in spring and fall but generally enter a resting state in summer and winter. As the soil starts to heat up and dry out in late spring (typically May in the North Central states), the shallow dwellers move a little deeper (perhaps 18 inches), curl up in a ball, and secrete a mucus to try to keep from drying out. They spend most of the summer in this state. In fall, when the soil starts to

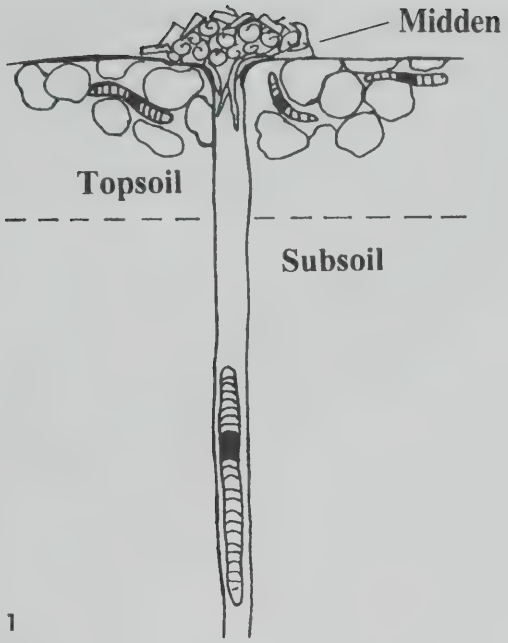



Figure 1

cool and become wetter, they become active, but then often enter into hibernation for the winter. The nightcrawlers also tend to be more active in spring and fall, but they may not go into a complete resting state in summer or winter because they can retreat to the bottom of their burrows during extremes of heat or cold. The best time to observe or count earthworm populations is early- to mid-spring (often April in North Central states), or late fall (November).

Earthworms have both male and female sexual organs. Most species require a partner for mating. During mating, sperm are exchanged and stored in one of the segments of the worm. The cocoon casing is then produced by the clitellum (the band seen on mature worms), and the worm "backs out" of the casing, depositing the sperm and eggs into the casing as it passes over the appropriate segments. The cocoon (2–4 mm in diameter) then incubates in the soil for several months, depending on soil conditions, before one young worm (or two for some species) emerges. New worms generally only emerge when soil moisture and temperature conditions are suitable.

## EFFECTS ON SOIL PROPERTIES

The degree of importance of earthworms in maintaining soil and crop productivity varies depending on circumstances. Earthworms are almost always beneficial, when present, but they may not be necessary. Some soils can be very productive without the presence of earthworms. The worms have sometimes been shown to improve crop growth and yield directly, but more often their activity affects crop growth indirectly through their effects on soil tilth and drainage.

Earthworms can have significant impacts on soil properties and processes through their feeding, casting, and burrowing activity. The worms create channels in the soil, which can aid water and airflow as well as root development. The shallow-dwelling worms create numerous small channels throughout the topsoil, which increases overall porosity and can help improve water and air relationships. Nightcrawlers create large vertical channels, which can greatly increase water infiltration under very intense rainfall or ponded conditions. Nightcrawler channels also can aid root proliferation in the subsoil, due both to the ease of root growth in a preformed channel and the higher nutrient availability in the cast material that lines portions of the burrow. Earthworm casts, in general, are higher in available nutrients than the surrounding mineral soil, because the organic materials have been partially decomposed during passage through the earthworm gut, converting the organic nutrients to more available forms.

Earthworms improve soil structure and tilth. Their casts are an intimate mixture of organic material and mineral soil and are very stable after initial drying. The burrowing action of the worms moves soil particles closer together near burrow walls, and the mucus secreted by the worms as they burrow also can help bind the soil particles together. Increased porosity and mixing of residues and soil are additional ways that earthworms improve soil structure.

The mixing of organic materials and nutrients in the soil by earthworms may be an important benefit of earthworms in reduced tillage systems, especially no-till. The earthworms may, in effect, partially replace the work of tillage implements in mixing materials and making them available for subsequent crops. In natural ecosystems such as forests, organisms recycle last year's leaf litter into the soil for release of nutrients. With no-till planting, earthworms and other soil organisms also may promote mixing. It seems appropriate, therefore, to try to determine how we can manage soils to encourage these organisms and their beneficial activity.

## MANAGEMENT IMPACTS ON EARTHWORMS

When soils are managed for crop production, management of the habitat in which earthworms and other organisms live also occurs. Management practices affect earthworm populations by affecting food supply (location, quality, and quantity), mulch protection (affects soil water and temperature), and chemical environment (fertilizers and pesticides). By considering how these factors are changed in different management systems, predictions about the general effects on earthworm populations can be made for systems that have not been studied.

Productive pasture fields usually have much higher earthworm populations than row-cropped fields, primarily because of the large amounts of organic materials that are continually being added to the soil. Continuous root growth and subsequent death and decay, plus animal manure, provide a large food supply that can maintain high earthworm populations. In addition, the pasture plants act as a mulch to buffer the soil against rapid changes in temperature. Pasture fields also are not usually tilled, and thus burrow systems are left undisturbed.

Within row-cropping systems, using tillage systems that leave surface residue, is one of the most important ways that earthworm populations can be influenced. No-till systems usually have higher earthworm populations than do conventional moldboard plow systems, due to increased food supply and mulch protection. With residues on the soil surface, the food supply is available to the earthworms for a longer time than if residues are incorporated with a tillage implement. In addition, the surface residues act as a mulch and slow the rate of soil drying in late spring and freezing in late fall, thereby lengthening the active periods for the worms, and allowing them to feed and reproduce longer in both spring and fall. Surface residue also gives the earthworms more time to acclimate to the summer or winter and enter their resting state. No-till is even more important for nightcrawlers than for the shallow-dwelling worms. Because nightcrawlers feed primarily on residues at the surface, pulling them into their permanent burrows, a clean-till system is not very conducive to nightcrawlers. The surface food supply is not present in plowed soils, and the top portion of the permanent burrow must be reformed after any tillage operation. Although a few nightcrawlers may be present in plowed fields, often they are absent.

Tillage systems that are intermediate between the extremes of moldboard plowing and no-till tend to have intermediate populations. The amount of surface residue cover is the key factor to consider when assessing different possible tillage practices for a field, as well as establishing conditions that encourage earthworm populations.

Data collected in Indiana and Illinois over 10 years confirms the generalizations just discussed. Earthworm populations were counted after 10 years of tillage plot history on a dark, poorly drained silty clay loam soil near West Lafayette (Table 1). Very few worms were found in the continuous corn plots under either plow or no-till, and there were no statistically significant differences between the two treatments. Populations were surprisingly low and may have been affected by drought conditions the summer before the survey.

The continuous soybean plots had higher populations than continuous corn, with no-till having more than twice the worm population of moldboard plowing. Earthworms generally prefer legumes as a food source over grasses, which probably is the main reason for the higher populations found in the soybean plots. The continuous corn plots also received applications of corn rootworm insecticide and anhydrous ammonia, both of which can kill some earthworms. However, the effect of these chemicals on overall field populations of worms is probably small. Ammonia kills a few worms right in the zone where it is injected, but some limited observations and counts before and after injection have suggested that less than 10% of the population is affected. Likewise, some corn rootworm insecticides kill earthworms, as can be seen by dead earthworms at the soil surface over the seed row. The overall effect on field populations is probably small,

**Table 1 ■ Earthworm populations on silty clay loam near West Lafayette, IN.**

| Crop* | Management* | Earthworms/m² |
|---|---|---|
| Cont. corn | Plow | 10 |
| Cont. corn | No-till | 20 |
| Cont. soybean | Plow | 60 |
| Cont. soybean | No-till | 140 |
| Bluegrass-clover | Alleyway | 400 |
| Dairy pasture | Manure | 340 |
| Dairy pasture | Manure (heavy) | 1,300 |

*Crop and Management systems had been continuous for at least 10 years.

**Table 2 ■ Earthworm populations (April) under corn–soybean rotation on slit loam soil in southeastern Indiana.**

| Tillage | Earthworms/m² | | |
|---|---|---|---|
| | 1987 | 1988 | 1989 |
| Chisel | – | 44 | 67 |
| Ridge-till | – | 189 | 178 |
| No-till | 156 | 133 | 211 |

however, as long as the material is banded or in-furrow so that only a small zone of soil is affected. A rotation of corn and soybean generally has higher earthworm populations than continuous corn, probably due in part to elimination of the rootworm insecticide use, but mainly due to inclusion of a legume in the system.

Earthworm populations were much higher in a pasture than in the row-cropped fields (Table 1). Where the manure of the grazing animals was augmented by heavy applications of manure from the barnyard, populations were very high. Animal manures, sewage sludges, and other organic wastes usually help build earthworm populations, although there may be an initial detrimental effect if there is a high concentration of ammonia in a slurry material.

Data from a poorly drained silt loam soil, low in organic matter, in southeastern Indiana illustrates some intermediate tillage practice effects as well as year-to-year variations (Table 2). Earthworm populations were counted in spring in a corn–soybean rotation. The fall chisel system had less worms than either ridge-till or no-till, due to much less residue cover. Ridge-till and no-till populations were comparable, with ridge-till having slightly more worms in 1988 and no-till slightly higher in 1989. Populations vary from year to year as well as within a year, due to weather conditions and food availability. There were no nightcrawlers present in any of these plots.

In April 1992 earthworm populations were surveyed on 14 pairs of farmers fields in central Indiana and Illinois. Each pair consisted of a no-till and tilled (usually chiseled) field on the same soil type, in a corn–soybean rotation, as close together as possible (usually less than 1 mile apart). Most of the no-till fields had been in no-till for at least 5 years. Soil types included two sandy loams, one loam, and the rest silt loams and silty clay loams. Shallow-dwelling earthworms were counted by excavating and hand-sorting soil. The presence or absence of significant nightcrawler populations was determined by observing whether nightcrawler middens were present in the field.

Results of the survey confirmed that no-till management generally leads to increases in earthworm populations. Eight of the 14 sites had higher populations in no-till than in tilled fields, with increases ranging from 25% higher to 10 times higher. Four sites had roughly equal populations under both systems, and two sites had slightly lower populations with no-till. Populations ranged from a low of 2 to a high of 340 earthworms per square meter over all the sites and tillage systems surveyed. In addition, nine no-till and only three tilled sites had significant nightcrawler activity, again confirming the strong influence of surface residues on nightcrawlers. We don't know whether the other no-till sites will develop nightcrawler populations after more time in the system.

## MANAGED AND/OR CHEMICALLY TREATED FIELDS

As discussed above, there are many conventional fields where nightcrawlers are completely absent, presumably due to lack of surface food supply. When these fields are switched to a no-till system, the habitat is better for the nightcrawlers, but the only way a population can get started is by overland movement from nearby places that have nightcrawlers, such as fencerows, roadsides, and grassed waterways. This process is slow and may take many years before a field is populated. In addition, not all roadsides and fencerows have nightcrawlers, so there may not be a "source" of nightcrawlers adjacent to every field. Finally, it is not clear whether nightcrawlers survive in all soil types, so some fields may be unsuitable even when managed for the worms. Much more study and observation of nightcrawlers in agricultural fields is needed to answer these questions.

The impact of agricultural chemicals on earthworm populations varies with the chemical. Inorganic nitrogen fertilizers promote greater plant production than in unfertilized fields and therefore higher earthworm populations. Although anhydrous ammonia kills a few worms in the narrow band where injected, field effects are probably minimal due to the small area affected. There is little information on other nitrogen sources commonly used in the Midwest, but effects are probably small when used at

typical field rates. Most herbicides used in crop production in the Midwest are harmless or only slightly toxic to worms and should not be a great concern. As discussed above, some corn rootworm insecticides are toxic to worms, but their effects can be reduced by keeping the application band as narrow as possible. In general, the organophosphate and pyrethroid insecticides are harmless to moderately toxic, whereas the carbamate insecticides and fungicides are highly toxic. Nematicides in general are also highly toxic.

## HOW TO ENCOURAGE EARTHWORMS

Earthworm populations can be increased by applying the concepts discussed above on food supply and surface mulch protection (Table 3). Leaving a surface mulch, by no-till or other conservation tillage systems with plenty of residue cover, generally increases earthworm populations. Growing winter cover crops may augment the mulch protection as well as provide additional food for the worms. Adding or growing organic matter is a great way to build earthworm populations. Animal manures and sewage sludges, and rotations with hay or set-aside fields, are also possible ways to provide more food for the earthworms and help increase populations. Soil pH should be maintained between 6.0 and 7.0 for optimum conditions, although lower pHs are tolerated by most species. Although management can increase earthworm populations on many soils, some soils cannot support high earthworm populations, regardless of management, due to inherent soil texture and drainage properties. Very coarse sands and perhaps high water table-heavy clays are two examples.

**Table 3 ■ Methods to increase earthworm populations.**

| |
|---|
| **Leave surface mulch** |
| No-till |
| Ridge-till |
| Cover crops |
| **Add or grow organic matter** |
| Manure |
| Hay |
| Set-aside |

## COVER CROPS

The question often arises, "Is it worthwhile to 'seed' earthworms in fields with low populations?" The first principle to remember is that the shallow-dwelling species are already established, and their current population is what can be supported by the current management system. If the management system is changed to something more suitable for the worms, their populations will increase quickly (1 or 2 years) to the level that can be supported by the new practices. Thus, there is little evidence to suggest that seeding these worms is worthwhile.

Nightcrawlers, however, may be a slightly different story. Because many conventional fields have no nightcrawlers present, a change in management from conventional to no-till does not guarantee that nightcrawlers will become established (see discussion above). Under these circumstances, there may be some benefit from establishing a few sources of nightcrawlers in the field, and several farmers have claimed success in establishing nightcrawlers in this way. Whether nightcrawlers would have established themselves in these fields without the farmers assistance is not known. To try this practice, collect local nightcrawlers from country roads or pastures on rainy spring nights or mornings is a good way to start. Purchasing nightcrawlers is expensive and they may not be adapted to local soils and climates. A small-scale, low-cost trial is highly advisable, because it is not known whether nightcrawlers survive in all soils. Protect the worms from the sun, and place four or five together under some mulch or residue in a spot every 30 or 40 feet in the field, preferably on a cloudy, wet, cool day. Record the location of the seeded spots and then observe those spots for evidence of midden activity over the year to determine whether the nightcrawlers survived and if the patches are growing.

## REMAINING QUESTIONS AND FURTHER INFORMATION

Many questions about earthworms and agricultural fields remain to be explored. How much do earthworms contribute to nutrient cycling and availability to an annual crop? How much improvement in soil physical properties can be expected from both shallow-dwelling species and nightcrawlers? Why are nightcrawlers present in some no-till fields and

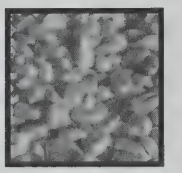
not others? What practical management strategies might be used to help establish nightcrawlers in areas that have none? These and other questions have potential importance for increasing the sustainability of agricultural systems. More detailed information about earthworms can be found in the books listed in the References. Reynolds (1977) focuses on morphology and taxonomy, including diagrams and a taxonomic key, for serious students of earthworm speciation. Most of the common species in agricultural fields of the central Corn Belt are included.

## REFERENCES


Edwards, C. A., and J. R. Lofty. 1977. Biology of Earthworms, 2nd. ed. Chapman & Hall, London. (3rd edition in preparation).

Lee, K. E. 1985. Earthworms: Their Ecology and Relationships with Soils and Land Use. CSIRO, Sydney Australia.

Reynolds, J.W. 1977. The Earthworms of Ontario. Royal Ontario Museum, Toronto.



# NUTRIENT MANAGEMENT CHALLENGES

**Dennis P. McKenna**

Agricultural land has been identified as a primary source of impairment of designated uses for streams and lakes in Illinois. Nutrients, siltation, and suspended solids are listed as principal causes of water quality impairments. In its most recent assessment of the quality of surface waters in the state, the Illinois Environmental Protection Agency (2002) identified nutrients as a potential cause of impairment for more than 50% of the impaired stream miles and more than 75% of impaired lake acres.

However, because the dynamics of aquatic system, particularly rivers and streams, are complex and often not well understood, identification of the true cause of an impairment and prediction of system responses to changes in inputs of potential pollutants are difficult. Some streams and lakes may have high nutrient concentrations, but do not exhibit eutrophication because of limited light availability due to shading or high inorganic turbidity.

Accurate targeting to achieve reductions in agricultural nonpoint sources is further complicated because potential pollutants from agriculture may have different chemistries and, consequently, different pathways to water bodies. For example, nitrate is a soluble, nonreactive chemical and is readily leached through soils, whereas phosphorus is slightly soluble and reactive in soils and the highest concentrations are in the upper soil layers. In Illinois, nitrate concentrations in streams and reservoirs are much higher in those areas of the state underlain by flat, black, tile-drained soils and sandy soils. Phosphorus loads attributable to agricultural nonpoint sources are highest in areas of the state with high runoff or erosion rates. In addition, different management practices are often necessary to reduce nitrate and phosphorus movement to surface water: nitrate best management practices (BMPs) modify infiltration, leaching, and soil water content; phosphorus BMPs modify surface runoff and erosion. In some instances, practices to reduce nitrate leaching and movement to surface waters may increase losses of phosphorus.

The Illinois Nutrient Management Task Force was established by Director Joe Hampton of the Illinois Department of Agriculture to address water quality issues related to agricultural nutrients, such as exceedences of the nitrate standard in public water supplies, total maximum daily loads (TMDLs), and hypoxia in the northern Gulf of Mexico.

The goal of the task force is to help the agricultural community move toward solutions by coordinating efforts to 1) assess the problem; 2) identify and promote nutrient BMPs; 3) identify any research and data needs; and 4) identify economic, institutional, and infrastructure problems and solutions. The task force includes policy-level representatives from a large number of agricultural, academic, and environmental organizations, and state and federal agencies.

Underlying the work of the task force is the recognition that, with limited state and federal resources for technical assistance and cost-sharing and an agricultural economy buffeted by high input costs and low commodity prices, accurate targeting will be critical to achieving water quality improvements. The task force members have agreed on several interim priorities for action.

The highest priority for state cost-share funds is assigned to watersheds where either the nitrate standard is exceeded in a public water supply or nutrients are listed as a cause of impairment on the

state's 303(d) list for development of a TMDL. In these areas, the department has diverted existing state funds to address the causes of impairment in TMDL watersheds and initiated a cost-share program for nutrient management.

Beginning in fiscal year 2003 (July 1, 2002), the department is shifting some of its resources to more directly address water quality concerns. It will target a portion of the Conservation Practices Program (CPP) budget for fiscal year 2003 to a limited number of soil and water conservation districts (SWCDs) with watersheds with identified water quality impairments. These funds will be designated for incentive payments to landowners/operators within that specific watershed to promote the use of management practices that reduce the movement of the specific pollutant causing the water quality impairment. If sediment or siltation is identified as the cause, traditional erosion control practices are eligible for the cost-share. If phosphorus is the cause of the impairment, the new conservation practice for developing nutrient management plans and traditional erosion control practices are eligible. However, if nitrate is the sole cause of the impairment, only the nutrient management plan conservation practice will be eligible for incentive payment with these targeted funds.

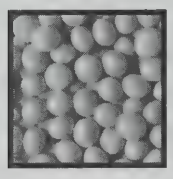
Nutrient management plans, which include soil testing, can be very effective in reducing movement of nutrients to water bodies. Initially, the nutrient management plan practice will only be available in SWCDs that have a watershed with a TMDL being developed. The cost-share will only be available to landowners/operators with land in the identified TMDL watersheds. The dollar amount allocated to each eligible SWCD is based on their portion of the total number of cropland acres in eligible watersheds.

The task force also concluded that phosphorus is the limiting nutrient in most surface waters in the state and should be a higher priority than nitrogen for educational and public information programs.

A technical working group, composed of university researchers and state and federal agency staff, has met to identify the most cost-effective management practices to reduce movement of nutrients to surface water. This group concluded that although some of the most widely used and promoted erosion control practices, such as conservation tillage, are very effective in reducing movement of phosphorus in the particulate form, e.g., phosphorus attached to sediment, these practices often do not reduce and, in fact, may increase losses of phosphorus in the dissolved form. For both nitrogen and phosphorus, it seems that more effort is necessary to encourage soil testing and fertilizer applications at no more than the agronomic rates.

## REFERENCES

Illinois Environmental Protection Agency. 2002. Illinois Water Quality Report 2002. Bureau of Water, Illinois Environmental Protection Agency. Springfield, IL. 506 pp.



# PESTICIDES, PARASITES, AND POLLYWOGS: HAZARDS VERSUS RISKS

**Allan S. Felsot**

Public perception will forever link pesticides with Rachel Carson's metaphor of a silent spring. Images of landscapes absent of birds will overshadow any benefits that pesticides have shown in stabilizing food production by protecting yields against a myriad of pests. After the "bird killer" DDT was vanquished, raptorial and fish-eating bird populations rebounded surprisingly rapidly. Since then, society has enjoyed the cacophony of birds only occasionally knocked cold by the neurotoxic insecticides still on the market.

Throughout the early history of modern pest control by synthetics, herbicides were untouched by infamy. Today, however, silent spring has turned into croaking frogs as worldwide amphibian population declines have been elevated to the status of new ecological disaster. And now herbicides commonly used in field crop production are in the cross hairs. Atrazine especially is the new DDT because recent articles (Hayes et al. 2002, Kiesecker 2002) have claimed it hazardous to pollywogs.

## A TALE OF TWO MALADIES

Actually, there are two stories here, but they have become intermingled and thus confused. On the one hand, amphibian declines have been documented around the world (Alford and Richards 1999). The laundry list of proposed factors singly or in combination precipitating the population crashes includes the following:

- increases in UV radiation due to zone holes;
- increased predation to the introduction of exotic predatory fish;
- interspecific competition with introduced species;
- habitat modification, including removal of trees, drainage of wetlands, and changes in vegetation structure;
- changes in water quality (for example, changes in pH, contamination by synthetic chemicals, including pesticides)
- increased parasitism and disease;
- global climate change; and
- synergistic interactions among any of the listed factors.

Ironically, the major amphibian population crashes have occurred in comparatively pristine habitats at higher elevations (Carey 2000). Thus, human associated factors such as pesticides or habitat modification are not good hypotheses. However, evidence has accumulated supporting the prevalence of a virulent pathogenic fungus (*Batrachochytrium dendrobatidis*, order Chytridiales) in diverse places such as Australia (Berger et al. 1998) and the mountains of Central America (Carey 2000). The fungus attacks the keratinized skin of juveniles and adults postmetamorphosis, and the frogs seem to lack immunocompetence to fight the fast-developing infection (Carey 2000).

The second story about frogs involves irresistible pictures of school kids holding multilegged malformed frogs collected from agriculturally dominated habitats. Hypotheses of human-induced toxicosis (Ouellet et al. 1997, Burkhardt et al. 1998) have been

generated faster than the flick of a frog's tongue catching a fly. Concerns temporally rose to a feverish pitch in Minnesota, where developmentally challenged frogs first made headlines, probably because University of Minnesota researchers had "linked" the incidence of birth defects with the use of pesticides (suggested by Kavlock 1998 in reference to Garry et al. 1996).

Recent research has shown experimentally and in the field that a trematode parasite (*Ribeiroia* spp.) infects tadpoles and may be the most widespread cause of limb deformities in collected frogs (Johnson et al. 1999, 2001, 2002; Kiesecker 2002). The parasite's primary hosts are snails (especially *Planorbella* spp.), but the trematode larvae migrate from the snail and burrow into the tadpoles in tissues destined for limb generation. The parasite hypothesis was further expanded to suggest that pesticides such as atrazine, malathion, and esfenvalerate may increase the susceptibility to infection by the trematode (Kiesecker 2002). However, the laboratory experiments generating the hypothesis tested pesticide concentrations over exposure periods far above anything plausible from field runoff into ponds. An ecoepidemiological investigation of trematode-infected frogs in the Pacific Northwest and the prevalence of limb malformations suggested that nutrient enrichment of ponds encouraged proliferation of snail populations and thus augmented trematode populations (Johnson et al. 2002). The most susceptible habitat seemed to be artificial impoundments associated with pastures used by dairy cattle.

Although every author likes to take credit for placing one more pieces into the puzzle of disappearing amphibians, the phenomenon of worldwide amphibian population crashes cannot be explained by the prevalence of malformed frogs (Carey 2000). Where individual frogs have been collected and documented in a scientifically designed field survey (Canfield et al. 2000, Johnson et al. 2002), the incidence of malformations is too low to account for disappearing populations. Studies in Minnesota, for example, show that malformation rates in the Northern leopard frog (*Rana pipiens*) can be as high as 20% and in the mink frog as high as 75%, but these numbers are the extremes from one pond and are only seen in captured juveniles, not breeding adults. Furthermore, the incidence rate varies from site to site and time of year, and the type of malformations (limbs, digits, and eyes) are also variable. Average malformation rates are generally less than 10%. But developmentally challenged frogs have always been present, just not at the seemingly high numbers observed mostly during the fall months (September and October) in Minnesota (Ouellet et al. 1997, Johnson et al. 2002).

Malformed frogs may be poor lovers, and therefore not likely to successfully mate, yet alone survive predators, parasites, and the rapidly changing conditions of the pond or wetland habitat. The significance of such individuals to the survival of a population in an isolated pond or wetland, which is very characteristic of the Corn Belt, is obscure. Pertinently, only a small percentage (i.e., <10%) of eggs laid by one female actually survive the rigors of development to become a sexually mature adult (Carey and Bryant 1995). Thus, in terms of maintaining a population, conserving breeding adults, which can lay hundreds to thousands of eggs, is more important than worrying about larvae (tadpoles) or a comparatively few malformed individuals. In the populations that have precipitously crashed, malformed frogs were decidedly not a causative factor (Carey 2000) nor were habitat modifications obvious.

## NEW HYPOTHESIS ON THE BLOCK

The latest hypothesis on the block to explain declining amphibian populations suggests that herbicides at environmentally relevant concentrations are interfering with normal sexual development (Hayes et al. 2002). Atrazine, in particular, has been blamed for a condition in frogs called intersex (or hermaphroditism) that is characterized by the presence of male and female gonads in a single individual that morphologically is male. At this point, however, the reproductive success of such individuals has not been elucidated, although the occurrence of intersex individuals in the field has been documented in frogs collected in Illinois (Reeder et al. 1998).

Atrazine residues have been detected in water collected from agricultural watersheds all over the United States, so potential exposure of frogs is likely. Laboratory studies suggest that atrazine can disrupt normal sexual development, perhaps through direct effects on the endocrine system. A new hazard has been identified for atrazine, but unknown is the risk (i.e., likelihood or probability) that environmental concentrations of atrazine actually adversely affects frog populations in the wild. Although some in our society would argue for implementation of the precautionary principle, and therefore the immediate

banning of atrazine, a more logical approach is to figure out whether the risk of atrazine effects are even worth worrying about. Thus, a risk assessment approach can be used to separate hazard identification from risk of an effect.

## RISK ASSESSMENT PARADIGM

Risk assessment as applied to pesticide technology is the determination of the potential hazards of a substance and the probability that it will cause harm to the environment and/or human health when used in the manner for which it is intended. Hazard is potential harm owing to the innate toxicity of a substance, but its manifestation is conditional to the circumstances of exposure. Risk is considered the probability that harm will occur and depends on the magnitude of exposure. Thus, risk assessment consists of four parts: hazard identification, dose-response characterization, exposure assessment, and risk characterization. Risk assessment depends on defining the problem to be analyzed, so simply stated, we want to know the likelihood that atrazine residues in the environment can cause the types of reproductive problems observed in the laboratory.

## IN SEARCH OF THE MOST SENSITIVE ENDPOINT

The purpose of hazard identification is to determine the array of possible physiological and biochemical effects on an organism that could potentially adversely affect its growth, development, and reproduction. Once the array of possible adverse responses is characterized, the risk assessor searches for the highest dose failing to cause the effect. For mammalian risk assessment, death is an irrelevant endpoint; rather, systemic effects such as tissue pathologies, weight loss, or enzyme dysfunction are examined. The toxicological endpoint for the most sensitive malady is described by the no observable adverse effect level (NOAEL).

For ecological risk assessment, death as measured by the $LC_{50}$ (lethal concentration to 50% of the tested animals) is frequently sought for short-term exposures (acute toxicity). For longer term exposures (chronic toxicity), reproductive life cycles are examined, and the concentration causing no impairment is called the no observable adverse effects concentration (NOAEC).

Based on studies of acute toxicity, milligram per liter (mg/l) levels of atrazine are necessary to cause death in tadpoles. The $LC_{50}$ based on mortality depends on the species tested. One of the most susceptible species tested is the American toad (*Bufo amercianus*); the $LC_{50}$ of atrazine to late-stage tadpoles was estimated to be 10.7 mg/l (Howe et al. 1998). For an even more sensitive endpoint, tadpole deformities, the NOEC was 2.6 mg/l (Allran and Karasov 2001).

Two independent studies have shown that African clawed frog (*Xenopus laevis*) tadpoles exposed to atrazine in water suffer from either intersex condition or impaired testicular development (Hayes et al. 2002, Tavera-Mendoza 2002). These hazards are plausible because atrazine can induce (enhance the activity of) aromatase, the enzyme that converts testosterone to estrogen (Sanderson et al. 2001, 2002). If genetically male animals do not have enough circulating testosterone then their gonads develop abnormalities in sperm production and/or morphologically female characteristics. Female frogs seem unimpaired by atrazine. Researchers thus far have not tested whether intersex males can mate normally and successfully reproduce, so ecologically relevant hazards of atrazine have not been tested.

In contrast to the milligram per liter concentrations causing frog mortality and malformations, microgram per liter (µg/l) concentrations seem to adversely affect the endocrine system and lead to putative sexual impairment. In frogs exposed to atrazine from hatch until metamorphosis (ca. 1.5 months), intersexuality was observed in 16–20% of exposed males over a concentration range of 0.1 to 25 µg/l (Hayes et al. 2002). These results are unusual because no defined dose-response function was obtained. In other words, the severity of toxicological effects usually increases with increasing dose, but in the Hayes et al. (2002) study, the response was the same at all doses. Nevertheless, no effect on sexual development was observed at the lowest dose tested, 0.01 µg/l. Another study showed effects on testes development at 21 µg/l, but this was the only dose tested (Tavera-Mendoza).

Under the risk assessment paradigm the most sensitive toxicological endpoint would be defined as the development of the intersex condition, and the NOEC associated with this endpoint is the empirically observed concentration of 0.01 µg/l atrazine. The actual NOEC is somewhere between 0.01 and 0.1 µg/l but was not empirically determined. Often, in the absence of a valid NOEC, EPA will use the lowest observable effect concentration (LOEC) and divide it

**Table 1 ■ Estimated environmental concentrations (EECs, μg/l) of atrazine based on EPA computer modeling by using a pond as the target aquatic system (data from U.S. EPA 2002b).**

| Crop | Application Rate | Peak Concentration | 4-day Average | 21-day Average | 60-day Average | 90-day Average |
|---|---|---|---|---|---|---|
| Corn | 2.0 | 38.2 | 38.0 | 37.2 | 35.5 | 34.2 |
| | 1.1 | 21.0 | 20.9 | 20.5 | 17.7 | 18.8 |
| Sorghum | 2.0 | 72.7 | 72.3 | 70.6 | 67.7 | 65.9 |
| | 1.2 | 43.6 | 43.4 | 42.4 | 40.6 | 39.5 |
| Sugarcane | 4.0 | 205 | 204 | 202 | 198 | 194 |
| | 2.6 | 133 | 133 | 131 | 129 | 126 |

by a factor of 3. Thus, it would not be unreasonable to assume an effective NOEC of 0.03 μg/l for the toxicological endpoint of intersex in laboratory exposed frogs.

## ATRAZINE EXPOSURE CHARACTERIZATION

The next step is to determine the level of exposure and thus the likelihood (or how often) such exposures will be realized. Two sources of exposure information can be used. The EPA determines ecological risk by running computer models to estimate atrazine concentrations (called EECs) in a stagnant pond of water 2 m (6 ft) in depth and 1 ha (0.47 acres) in surface area. The other source of useable data is the results from the U.S. Geological Survey National Water Quality Assessment Project (NAWQA) (Larson et al. 1999). The NAWQA Project has monitored pesticide residues in 36 major agricultural and urban watershed basins of the United States. The NAWQA focus has been streams and rivers rather than ponds, so its relevance to frog populations breeding in ponds and wetlands may be somewhat questionable. However, the NAWQA data do represent runoff-derived residues. On-farm ponds would periodically experience direct pesticide runoff events, and wetlands would be drainage sinks for streams that also received runoff.

The latest draft of EPA's Registration Eligibility Decision Document (RED) for atrazine has presented both the modeled atrazine residues and in a semi-probabilistic form the distribution of atrazine residues from the U.S. Geological Survey NAWQA Project. The residue concentrations shown in Table 1 represent the EECs determined by computer modeling of three application scenarios to different crops. Note that EPA has assumed very little dissipation of atrazine from the virtual ponds because the concentration 90 days after application differed little from peak (or initial) concentrations.

The residues shown in Table 2 represent data generated by the U.S. Geological Survey from water samples collected across the United States. The presentation of the data as percentiles of concentration help elucidate the likelihood that a residue will be no bigger than a given value. For example, the median concentration (50th percentile) for atrazine from the entire agricultural watershed database is 0.027 μg/l. Thus, half of the collected water samples can be expected to be above this concentration, and half below it. At the 95th percentile, only 5% of the concentrations would exceed 3.25 μg/l.

**Table 2 ■ Distribution of measured atrazine residues reported as percentile concentrations (μg/l) in the U.S. Geological Survey NAWQA database as reported by EPA (data from U.S. EPA 2002b).**

| Basin Type | Maximum μg/l | 99th Percentile | 95th Percentile | 90th Percentile | 50th Percentile |
|---|---|---|---|---|---|
| Agriculture | 120 | 13 | 3.25 | 1.2 | 0.027 |
| Urban | 14 | 2.75 | 0.65 | 0.33 | 0.041 |
| Integrator | 27 | 12.5 | 5.35 | 1.95 | 0.062 |

## RISK CHARACTERIZATION

The probability of adverse effects to individual members of a population is calculated as the ratio of the estimated environmental concentration to the relevant toxicological endpoint ($LC_{50}$ or NOEC) for the most sensitive acute or chronic endpoint. EPA calls the resulting calculation the risk quotient (RQ). The lower the magnitude of the RQ, the more likely that no harm would occur from exposure to atrazine in the environment. For acute toxicity, the EPA uses the $LC_{50}$ and is unconcerned if the ratio is 0.5 or less. For chronic toxicity, the NOEC is used, and the estimated environmental concentration should be equal to or less than the NOEC (i.e., the RQ should be less than or equal to 1).

If death of amphibians by atrazine exposure were of concern then the RQ would range from 0.002 to 0.0003, depending on whether the EPA modeling data or the 95th percentile U.S. Geological Survey NAWQA monitoring data were used (Table 3). Similarly, RQs for tadpole malformations also would be significantly below 0.01 and thus far below EPA's RQ of concern (0.5). In contrast to the RQs based on endpoints of lethality and malformations, RQs based on sex organ development (i.e., intersex) indicate a high risk for hazard from exposure to modeled atrazine EECs as well as actually measured residues at the 95th percentile for all stream samples (Table 3).

In the EPA's ecological risk assessment, the agency noted the reports of endocrine system effects on frogs, but chose not to use them for risk characterization. The EPA traditionally has used the most sensitive fish species and aquatic invertebrate (usually *Daphnia* spp.) tested to determine aquatic ecological risk. The toxicological endpoint commonly use is the NOEC based on a life cycle test that examines reproductive success, rather than just on a histological examination of the gonads. Nevertheless, the little exercise in risk calculations illustrated in Table 3 show how perception of risk changes as hazard is changed to ever more subtle toxicological endpoints.

## REALITY CHECKS

Once a risk characterization is completed, it is a good time to take a reality check to determine whether field observations are consistent with the armchair-driven risk assessment outcome. Of course, the risk assessment is only as good as the data that is put in to it. However, if a pesticide is characterized as being particularly risky then an extensive history of use should give some noticeable ecological effects.

Syngenta, which is the registrant of atrazine, conducted its own laboratory experiments to determine the relationship between dose and intersex. The company reported to the EPA that it found no effect in *X. laevis* frogs after exposure to concentrations ranging from 0.01 to 25 µg/l (reported in U.S. EPA 2002a). The EPA commented that Syngenta's data were preliminary and lacked enough detail for comparison to the published study of Hayes et al. (2002).

At this point in time few field studies have reported the occurrence of intersex adult frogs. One study of ponds in New Hampshire reported two intersex individuals of more than 1,400 frogs examined (Sower et al. 2000). No information was given about possible atrazine contamination. A study in Illinois reported an intersex incidence rate of 2.7% for cricket frog (*Acris crepitans*) collections during 1993–1995

**Table 3 ■ Ecological risk characterization of atrazine based on calculations of RQs by using lethality and endocrine effects (intersex) as toxicological endpoints and residue concentrations derived from EPA computer modeling and the U.S. Geological Survey NAWQA database (agricultural basins) (based on U.S. EPA 2002b).**

| Toxicological Endpoint | EPA Modeling of EEC Residues | | NAWQA Pesticide Residue Data | |
|---|---|---|---|---|
| | 4-day Average | 90-day Average | 50th Percentile | 95th Percentile |
| Lethality ($LC_{50}$, 10700 µg/l) | 0.002 | 0.0018 | 0.000003 | 0.0003 |
| Tadpole malformations (NOEC, 2600 mg/l) | 0.008 | 0.007 | 0.00001 | 0.0013 |
| Intersex (NOEC, est. 0.03 µg/l) | 697 | 626 | 0.9 | 108 |

(Reeder et al. 1998). This incidence rate represented very few individuals and was not significantly correlated with the occurrence of atrazine in ponds. Pertinently, the concentrations in the water bodies ranged from ~1 to 15 µg/l).

Based on very limited field observations, intersex does not seem common. However infrequent intersex frogs are, they are not an unnatural occurrence. Examinations of museum specimens of cricket frogs revealed that preserved individuals archived long before the advent of atrazine exhibited a low rate of intersex individuals (V. Beasley, University of Illinois, personal communication, Oct. 17, 2002).

## EPA IS THE FAT LADY

The agrochemical manufacturing industry has garnered the reputation that it can push the EPA around when it makes its decisions about registering chemicals. However, any registration specialist at any chemical company will tell you that EPA definitely has the upper hand. In the Registration Eligibility Decision (RED) documents about atrazine ecological risk, the EPA concluded that atrazine was a particularly risky chemical for aquatic life (U.S. EPA 2002b). However, EPA did an end run around fish and aquatic invertebrates toxicity data and used an NOEC for the effects on aquatic vegetation that was in the realm of endocrine effects on frogs. Thus, using a NOEC of 2.3 µg/l and the distribution of NAWQA data, its own modeled EECs, and a probabilistic analysis of how often water concentrations would exceed the endpoint, EPA concluded that atrazine posed a high risk for ecological hazards.

Currently, the EPA's revised RED for ecological risk, which was issued during April 2002, is still out for comment. Six years ago, when the Food Quality Protection Act was passed, pundits predicted the demise of many pesticides owing to excessive exposure to residues in food and water. For nearly all compounds still registered, dietary and drinking water concerns have evaporated as better data on residues and consumption have been used. However, the Achilles heel for many pesticides has shifted to ecological risks. Many are not passing EPA's litmus test. Atrazine is certainly in water everywhere, but its fate may rest solely on EPA's decisions based on ecological hazards. All who worry that EPA gives in easily to the wishes of chemical companies should remember that registration isn't over until the EPA sings.

## REFERENCES


Alford, R. A., and S. J. Richards. 1999. Global amphibian declines: a problem in applied ecology. Annu. Rev. Ecol. Syst. 30: 133–165.

Allran, J. W., and W. H. Karasov. 2001. Effects of atrazine on embryos, larvae, and adults of anuran amphibians. Environ. Toxicol. Chem. 20: 769–775.

Berger, L., R. Speare, P. Daszak, D. E. Green, A. A. Cunningham, C. L. Goggin, R. Slocombe, M. A. Ragan, A. Hyatt, K. R. McDonald, H. B. Hines, K. R. Lips, G. Marantelli, and H. Parkes. 1998. Chytridiomycosis causes amphibian mortality associated with population declines in the rain forests of Australia and Central America. Proc. Natl. Acad. Sci. USA 95: 9031–9036.

Canfield, J. T., S. M. Kersten, and P. Vanselow. 2000. 1997–1999 Field season report: Minnesota malformed frog investigation. Minnesota Pollution Control Agency, Minneapolis, MN. 75 pp.

Carey, C., and C. J. Bryant. 1995. Possible interrelations among environmental toxicants, amphibian development, and decline of amphibian populations. Environ. Health Perspect. (suppl 4): 13–18.

Carey, C. 2000. Infectious Disease and Worldwide Declines of Amphibian Populations, with Comments on Emerging Diseases in Coral Reef Organisms and in Humans. Environ. Health Perspect. 108 (suppl 1): 143–150.

Garry, V. F., D. Schreinemachers, M. E. Harkins, and J. Griffith. 1996. Pesticide applicators, biocides, and birth defects in rural Minnesota. Environ. Health Perspect. 104: 394–399.

Hayes, T. B., A. Collins, M. Lee, M. Mendoza, N. Noriega, A. A. Stuart, and A. Vonk. 2002. Hermaphroditic, demasculinized frogs after exposure to the herbicide atrazine at low ecologically relevant doses. Proc. Natl. Acad. Sci. USA 99: 5476–5480.

Howe, G. E., R. Gillis, and R. C. Mowbray. 1998. Effect of chemical synergy and larval stage on the toxicity of atrazine and alachlor to amphibian larvae. Environ. Toxicol. Chem. 17: 519–525.

Johnson, P. T. J., K. B. Lunde, E. G. Ritchie, and A. E. Launer. 1999. The effect of trematode infection on amphibian limb development and survivorship. Science 284: 802–904.

Johnson, P. T. J., K. B. Lunde, R. W. Haight, J. Bowerman, and A. R. Blaustein. 2001. *Ribeiroia ondatrae* (Trematoda: Digenea) infection induces severe limb malformations in western toads (*Bufo boreas*). Can. J. Zool. 79: 370–379.

Johnson, P. T. J., K. B. Lunde, E. M. Thurman, E. G. Ritchie, S. N. Wray, D. R. Sutherland, J. M. Kapper, T. J. Frest, J. Bowerman, and A. R. Blaustein. 2002. Parasite (*Ribeiroia*

*ondatrae*) infection linked to amphibian malformation in the western United States. Ecol. Monogr. 72:151–168.

Kavlock, R. J. 1998. What's happening to our frogs? Environ. Health Perspect. 106: 773–774.

Kiesecker, J. M. 2002. Synergism between trematode infection and pesticide exposure: a link to amphibian limb deformities in nature? Proc. Natl. Acad. Sci. USA 99: 9900–9904.

Larson, S. J., R. J. Gilliom, and P. D. Capel. 1999. Pesticides in streams of the United States—initial results from the National Water Quality Assessment Program. U.S. Geological Survey Water-Resources Investigation Report 98-4222, Sacramento, CA. 99 pp (downloaded as PDF file from http://water.wr.usgs.gov/pnsp/).

Ouellet, M., J. Bonin, J. Rodrigue, J. L. DesGranges, and S. Lair. 1997. Hind limb deformities (ectromeilia, ectrodactyly) in free-living anurans from agricultural habitats. J. Wildlife Dis. 33: 95–104.

Reeder, A. L., G. L. Foley, D. K. Nichols, L. G. Hansen, B. Wikoff, S. Faeh, J. Eisold, M. B. Wheeler, R. Warner, J. E. Murphy, and V. R. Beasley. 1998. Forms and prevalence of intersexuality and effects of environmental contaminants on sexuality in cricket frogs (*Acris crepitans*). Environ. Health Perspect. 106: 261–266.

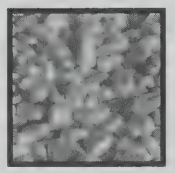
Sanderson, J. T., R. J. Letcher, M. Heneweer, J. P. Giesy, and M. van den Berg. 2001. Effects of chloro-s-triazine herbicides and metabolites on aromatase activity in various human cell lines and on vitellogenin production in male carp hepatocytes. Environ. Health Perspect. 109: 1027–1031.

Sanderson, J. T., J. Boerma, G. W. A. Lansbergen, and M. van den Berg. 2002. Induction and inhibition of aromatase (CYP19) activity by various classes of pesticides in H295R human adrenocortical carcinoma cells. Toxicol. Appl. Pharmacol. 182: 44–54.

Sower, S. A., K. L. Reed, and K. J. Babitt. 2000. Limb malformations and abnormal sex hormone concentrations in frogs. Environ. Health Perspect. 108: 1085–1090.

U.S. EPA. 2002a. EFED review of comments from Syngenta and its contractors about the EPA revised environmental risk assessment for atrazine. Available as PDF file from http://www.epa.gov/pesticides/reregistration/status.htm

U.S. EPA. 2002b. Reregistration eligibility science chapter for atrazine environmental fate and effects chapter. Available as PDF file from http://www.epa.gov/pesticides/reregistration/status.htm



# STATUS OF ILLINOIS STREAMS AND INLAND LAKES, 305(B) REPORT

**Gregg Good**

## OVERVIEW

The 2002 Illinois Water Quality Report was prepared by the Illinois Environmental Protection Agency (Illinois EPA) to satisfy reporting requirements in Section 305(b) of the Federal Clean Water Act (CWA). This report provides an assessment of the quality of the state's surface and groundwater resources, based on data collected through September 2000. Since 1990, the Illinois EPA also has provided a summary of this comprehensive report for general distribution to the public. The summary and links to additional useful information will be available on the Illinois EPA Web site at www.epa.state.il.us.

## THE 305(B) PROCESS

According to Section 305(b) of the Clean Water Act (a generic name that refers collectively to the Federal Water Pollution Control Act of 1972, the CWA of 1977, and subsequent amendments) and guidance provided by the United States Environmental Protection Agency (USEPA), each state must prepare and submit annually to the U.S. Congress and the USEPA a report that describes the resource quality of the surface and groundwaters of the state. Every other year, this report, commonly referred to as the "305(b) report," must be provided in written form, whereas in alternate years each state may submit an electronic database to meet the reporting requirement. In the 305(b) report, states also must explain how they determined the resource quality of the waters of the state in terms of the degree to which predefined beneficial uses (i.e., designated uses) of those waters are attained (i.e., supported). Also in the 305(b) report, when any designated use for any waterbody is not fully supported (i.e., impaired), the state must report potential reasons (causes and sources) for the impairment. Herein, I explain how Illinois EPA determines the quality of Illinois streams (throughout this report, streams and rivers are collectively referred to as "streams"), inland lakes, Lake Michigan, and groundwater resources. I also explain how to determine the potential causes and sources of resource-quality impairment, when it is found.

Because water-resource data take time to gather and process, each 305(b) report reflects a 2-year data lag. In this report, only surface water bodies for which new information became available since the last report (the 2001 report based on data collected through September 1999) were assessed. Therefore, surface water assessments will be based primarily on biological, water, sediment, in-stream habitat, and fish-tissue samples collected through September 2000 in conjunction with various ongoing monitoring programs. These programs include the Ambient Water Quality Monitoring Network (AWQMN), Intensive Basin Surveys (IBS), Facility-Related Stream Surveys (FRSS), the Ambient Lake Monitoring Program (ALMP), the Illinois Clean Lakes Monitoring Program (ICLP), the Volunteer Lake Monitoring Program (VLMP), and the Lake Michigan Monitoring Program (LMMP). Similarly, chemical and biological water resource data were collected on groundwater resources throughout the state to detect impairments. Groundwater quality monitoring programs include the Ambient Network of Community Water Supply Wells (CWS Network), Pesticide Monitoring Subnetwork of the CWS Network, Rotating Monitoring

**Table 1 ■ Assessment of Illinois stream resources.**

| 305(b) Reporting cycle (data through year indicated) | Assessment category | | Total stream miles assessed | % of Total stream miles |
|---|---|---|---|---|
| | Evaluated miles | Monitored miles | | |
| 2000 Report (1998) | 4,179 | 11,125 | 15,304 | 17.6 |
| 2001 Report (1999) | 3,992 | 11,578 | 15,570 | 17.9 |
| 2002 Report (2000) | 5,014 | 10,919 | 15,933 | 18.3 |

Network, and Dedicated Pesticide Monitoring Well Network.

Because a limited number of waterbodies and groundwater resources can be sampled in a single year, some monitoring programs (e.g., IBS for streams) are designed to achieve statewide coverage over a longer period (e.g., 5 yr). For these programs, in any single year, monitoring is focused in particular regions of the state (specific river basins) or at particular locations (e.g., highly susceptible CWS wells). For example, in 2000, sampling for the IBS monitoring program focused on the Big Muddy, Kankakee/Iroquois, Mackinaw, Mississippi North, Ohio, Saline and Spoon River basins. Sampling for the IBS program will not focus on these basins again until 2005.

## STREAMS

For this 2002 305(b) report, 15,933 stream miles was assessed for degree of use support (Table 1). In other words, 18.3% of the total stream miles (87,110) in the state have been assessed for attainment of at least one designated use. The degree of use support for a waterbody is determined by an analysis of all available information, including biological, physical/chemical, habitat, and toxicity data. For each applicable designated use, each waterbody is assessed as "good" (fully supporting or fully supporting but threatened), "fair" (partially supporting), or "poor" (not supporting). *Overall* use was fully or partially supported at 98.6% of all stream miles assessed for this use (i.e., 15,491 miles; Figure 1). For nearly all streams, assessments of *overall use* simply repeat the *aquatic life* use results because aquatic life is considered to be the most comprehensive reflection of overall resource quality in streams. However, for approximately 80 miles of modified streams in northeastern Illinois, *overall use* assessments directly reflect results for *indigenous aquatic life* use. Among all designated uses, the major potential causes of impairment (i.e., partially supporting or not supporting the use) in Illinois streams are nutrients, organic enrichment/low dissolved oxygen, habitat alterations, polychlorinated biphenyls, pathogens (fecal coliform bacteria), metals, siltation, and suspended solids. The major potential sources of impairment are agriculture, hydromodification, municipal point sources, resource extraction, and urban runoff/storm sewers.

## INLAND LAKES

For this 2002 report, 150,707 lake acres was assessed for at least one use. This number represents 60.5% of total lake acreage (248,922) in the state (Table 2). As for streams, each lake is assessed as good (fully supporting or fully supporting but threatened), fair (partially supporting) or poor (not supporting), for each applicable designated use. For lakes, *overall* use is a composite of up to five individual lake uses assessed: *aquatic life, public water supply, fish consumption, primary contact (swimming),* and *secondary contact (recreation).* Of the 148,134 lake acres assessed for *overall* use, 97.7% of the total lake number and 97.4% of the total lake acres are fully or partially supporting *overall* use. The major causes of impairment include nutrients, siltation, suspended solids, and excessive algae growth/high chlorophyll a concentrations. The major sources of impairment include agriculture, habitat modifications, bank or shoreline modification or destabilization, and runoff from forest, grassland or parkland (e.g., lawn or parkland fertilization or leaf litter/forest bed runoff).

## LAKE MICHIGAN

Lake Michigan is monitored annually through a cooperative agreement between the city of Chicago-Department of Water and Illinois EPA-Bureau of Water. The state of Illinois has jurisdiction over approximately 1 million acres and 63 shoreline miles of Lake Michigan bordering Cook and Lake counties in the northeastern corner of the state. *Overall* use

was fully supported at 100% of the 63 miles of shoreline assessed for this use. Results of assessments of *overall use* simply repeat the *aquatic life* use results because aquatic life is considered to be the most comprehensive reflection of overall resource quality in Lake Michigan.

## GROUNDWATER

Public water systems using groundwater as a drinking water source serve approximately 4.1 million people in Illinois. Illinois continues to address groundwater protection by accomplishing goals established in the Illinois Groundwater Protection Act (1987) and through federal, state, and local groundwater protection partnerships. These partnerships have used regulatory and nonregulatory programs to achieve success. Because approximately 1 million people in Illinois rely on unconfined aquifers for their source of drinking water, Illinois has placed added emphasis on the protection of these susceptible systems. Based on select contaminants from the 1998–1999 ambient groundwater quality monitoring program, the Illinois EPA estimates approximately 1.4% of the susceptible unconfined aquifer wells in the state are experiencing violations of groundwater standards and up to 4.0% are detecting contaminants above detection limits (but less than the standard).

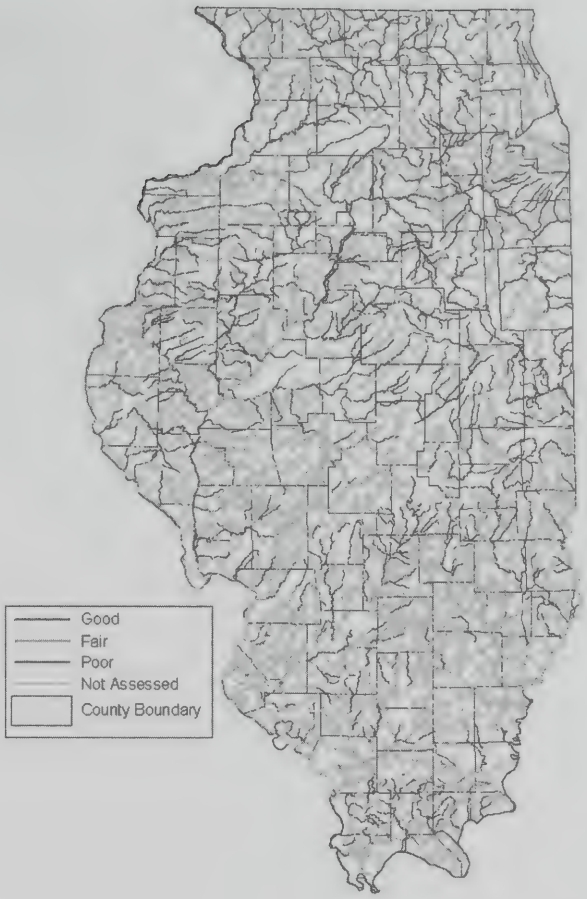
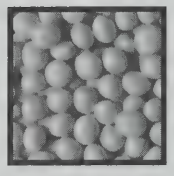



**Figure 1 ■ Condition of Illinois streams 2002 – *Aquatic Life* Use.** A colored version of this figure can be found on page 3 of the *Illinois Water Quality Report: 2002* found at http://www.epa.state.il.us/water/water-quality/report-2002/305b-2002.pdf.

**Table 2 ■ Assessment of Illinois inland lake resources.**

| 305(b) Reporting cycle (data through year indicated) | Total number of lakes assessed | Assessment category | | Total lake acreage assessed | % of Total lake acreage |
|---|---|---|---|---|---|
| | | Evaluated acreage | Monitored acreage | | |
| 2000 Report (1998) | 348 | 42,390 | 112,405 | 154,795 | 62.2 |
| 2001 Report (1999) | 369 | 40,149 | 116,845 | 156,994 | 63.1 |
| 2002 Report (2000) | 369 | 52,836 | 97,871 | 150,707 | 60.5 |



# ON-FARM CONTAINMENT AND OTHER STATE REGULATORY CHANGES FOR 2003

**Warren D. Goetsch**

In 2002, the Illinois Department of Agriculture developed, proposed and adopted changes to the Agrichemical Containment Program (8 Ill. Adm. Code 255); the Lawncare Spill, Wash Water, and Rinsate Collection Program (8 Ill. Adm. Code 256); the Land Application Authorization Program (8 Ill. Adm. Code 258); the Agrichemical Facilities Response Action Program (8 Ill. Adm. Code 259); the Illinois Noxious Weed Law (8 Ill. Adm. Code 220); and the Insect Pest and Plant Disease Law (8 Ill. Adm. Code 240). Some of the rule changes were significant, whereas others were only minor in nature. In addition, the Department of Agriculture developed, proposed, and adopted an emergency rule regarding pesticide licensing in response to the West Nile Virus outbreak (8 Ill. Adm. Code 250). The following is a brief synopsis of each of these rulemakings.

## ON-FARM CONTAINMENT

The most significant rulemaking in 2002 involved the addition of a third tier of regulated entities within the agrichemical facility containment program. The original rule limited regulated sites to agrichemical facilities and noncommercial facilities. An agrichemical facility is defined as a site used for commercial purposes where 1) bulk pesticides are stored in a single container in excess of 300 gallons of liquid pesticide or 300 pounds of dry pesticide for more than 30 days per year; or 2) where more than 300 gallons of liquid pesticide or 300 pounds of dry pesticide is being mixed, repackaged, or transferred from one container to another within a 30-day period; or 3) a site where bulk fertilizers are stored, mixed, repackaged, or transferred from on container to another. A noncommercial agrichemical facility is defined as a site, including the land and structures and equipment fixed thereon, designed and used for the storage, handling, and noncommercial application of pesticides and fertilizers in excess of certain amounts in a 45-day period, usually 300 gallons of bulk liquid pesticides, 300 pounds of bulk dry pesticides, 5,000 gallons bulk liquid commercial fertilizer, and 50,000 pounds dry commercial fertilizer (see 8 Ill. Adm. Code 255.10 for specific definitions).

In short, facilities that, over a certain time period, handled over a certain threshold amount of materials used for commercial purposes are defined as commercial facilities and are subject to specific containment requirements, including, but not limited to secondary containment (diking), operational containment (loading and unloading pads), operational and management practice plans, water supply protection, weekly inspections, and monthly inventories. Facilities not used for commercial purposes, but handling over a certain threshold amount of materials, are classified as a noncommercial and are required to provide containment. Due to the rather limited definition of a noncommercial facility, since the original effective date of the regulation (January 1, 1990) only six facilities have met the noncommercial facility definition.

The 2002 amendments to the rule define a new class of facilities and a corresponding new set of containment requirements. An on-farm storage facility is defined as a permanent site, including the land and structures and equipment fixed thereon, that 1) is designed and used for the noncommercial storage of

pesticides or fertilizers for more than 45 consecutive days in a single, nonmobile container holding in excess of 300 gallons bulk liquid pesticides or 300 pounds bulk dry pesticides or 5,000 gallons bulk liquid fertilizer or 50,000 pounds bulk dry commercial fertilizer; 2) is not used for commercial purposes; and 3) is not a noncommercial agrichemical facility. The new class of facilities was created to address the recent increase in the installation of on-farm storage tanks for the storage of bulk pesticides and bulk fertilizers. Recognizing that such facilities may store products for a long period but are not engaged in the transferring of product more than 45 days, the containment requirements for such facilities only include secondary containment structures such as diking. Operational area containment structures and systems are not specifically required. Also, the various recordkeeping and inspections requirements associated with commercial and noncommercial facilities are not required of on-farm storage facilities.

The compliance process for existing and new on-farm storage facilities is very similar to the original agrichemical containment rule in that owners and operators of on-farm storage facilities will be required to register their sites, apply for a permit (includes the submittal of detailed plans and specifications), and construct containment structures by specific deadline dates as follows: 1) register with the Department of Agriculture on or before March 31, 2003; 2) submit permit application on or before March 31, 2004; and 3) complete construction on or before June 30, 2005.

Specific requirements regarding containment volumes, containment hydraulic conductivity, construction materials, and facility operations are included in the regulation. As always, Department of Agriculture staff are available for assistance in developing containment strategies as well as completion of the various application forms.

## LAWNCARE PROGRAM CHANGES

The Lawncare Products Application and Notice Act [415 ILCS 65] was amended by the General Assembly in 2001 (Public Act 92-0113) to require that the loading of pesticides and fertilizers for distribution to a customer into application devices be conducted within a containment structure. The original act only required that the washing or rinsing of application devices at a facility be conducted within a permitted structure. As a result of the statutory change, the containment rules for lawncare facilities were amended to be consistent with the act.

## LAND APPLICATION AUTHORIZATION PROGRAM AND AFRAP

In addition to amending the Lawncare Products Application and Notice Act, Public Act 92-0113 also amended certain provisions of the Illinois Pesticide Act. One of those amendments expanded the scope of the department's land application authorization program to include soil and groundwater contaminated as a result of a release of an agrichemical during transport between the agrichemical facility and the field of application or at the field of application. These changes allow the Department of Agriculture to oversee the land application of contaminated soils and groundwater resulting from transportation incidents or in-field spills in addition to releases at a facility site. The requirements for Department of Agriculture authorization remain essentially the same as before except for a few updates to the requirements that were necessary to make the regulation consistent with a companion rule, the Agrichemical Facility Response Action Program (AFRAP) (8 Ill. Adm. Code 259). The AFRAP rule, which allows for Department of Agriculture oversight of remediation activities at agrichemical facility sites, was completed and became effective on February 2, 2002.

## NOXIOUS WEED LAW

As a result of a cooperative agreement between the Department of Agriculture and the Department of Natural Resources, the Department of Agriculture proposed the addition of the invasive species kudzu (*Pueraria lobota*) to the Illinois noxious weed list. This proposal was made by the director after consultation with the dean of the University of Illinois College of Agriculture, Consumer, and Environmental Sciences and the director of the Agriculture Experiment Station. According to the Department of Natural Resources, kudzu infestations in Illinois are currently limited to approximately 318 acres and a successful eradication program is still possible. With this change, kudzu becomes the eighth species on the state's noxious weed list.

In addition to amending the noxious weed list, the Department of Agriculture made various technical corrections and updates to the regulation.

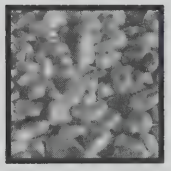
## INSECT PEST AND PLANT DISEASE LAW

In consultation with the nursery industry, the Department of Agriculture reviewed the fee structure associated with the state's nursery inspection program. The review demonstrated that the fees, which had not been adjusted for over a decade, were not adequate to support the program. As a result, the Department of Agriculture proposed and received approval for the updating of various fees as shown at right.

| Fee type | Past rate | Amended rate (eff. 1/03) |
|---|---|---|
| Nursery inspection fee: | | |
| < or =1 acre | $15 | $25 |
| >1 acre and < or =5 acres | $20 | $30 |
| >5 acres and < or =10 acres | $25 | $40 |
| >10 acres and < or =50 acres | $35 | $50 |
| >50 acres and < or =100 acres | $50 | $75 |
| >100 acres and < or =250 acres | $100 | $150 |
| >250 acres and < or =500 acres | $125 | $200 |
| >500 acres | $0.35 per acre | $0.50 per acre |
| Nursery dealer certificate | $15 | $25 |
| Special inspections | $15 per hour and $10 per certificate | $25 per hour and $25 per certificate |
| Original certificates | $10 per certificate | $25 per certificate |

## EMERGENCY RULEMAKING REGARDING WEST NILE VIRUS

As a result of the West Nile Virus outbreak and concern that there were not an adequate number of properly licensed individuals for the application of mosquito larvicides, the Department of Agriculture developed an emergency rule, amending 8 Ill. Adm. Code 250 at Section 250.210 and allowing for an expedited training and certification process. Under the provisions of the emergency rule, a properly licensed applicator may train others to properly apply a small number of specifically identified larvicides. The emergency rule prescribed the training subject matter, training time, reporting procedures, approved larvicides, and effective period. As of approximately 2 wk before the termination date of the emergency rule (October 31, 2002), 47 training sessions had been held and 601 persons had been qualified to apply the specific larvicides. The Department of Agriculture has also scheduled and held additional training and testing sessions under the normal certification program for mosquito abatement and plans to hold additional clinics over the winter. Hopefully, this initiative will ensure that an adequate number of properly licensed applicators and operators are available during the next treatment season if the West Nile Virus causes increased need for such control services.



# JAPANESE BEETLES AND WESTERN CORN ROOTWORMS: OLD INSECT FOES PRESENT NEW CHALLENGES

**Michael E. Gray, Jared Schroeder, and Kevin L. Steffey**

## A SUMMER TO REMEMBER

The summer of 2002 will be remembered by many producers as one that proved challenging regarding the management of two beetle species in their corn and soybean fields. These two insect species, Japanese beetle (*Popillia japonica* Newman) and the western corn rootworm (*Diabrotica virgifera virgifera* LeConte), were both "featured" many times this past season in our *Pest Management and Crop Development Bulletin*. Many farmers, particularly those in east central Illinois, indicated that they couldn't recall a summer in which densities of Japanese beetles had reached the sobering levels experienced in 2002. Provided are some observations pulled from the 2002 *Pest Management and Crop Development Bulletin* that illustrate a chronology of events regarding the most recent Japanese beetle experience.

- **Issue No. 5, April 26**—Kevin Black, Growmark Company, found Japanese beetle grubs in Randolph County.
- **Issue No. 13, June 21**—Entomologists at Purdue University reported the first sighting of Japanese beetle adults on June 12 in the Evansville area (near White County).
  - "Take note of this occurrence because, based on reports of grub injury this year, we could witness some large numbers of this pest this year." —K. Steffey
- **Issue No. 14, June 28**—Several reports were received of Japanese beetle infestation, and even rose gardens.
  - On June 25, Kevin Black, reported that Japanese beetles were clipping silks within a cornfield located near Waterloo, Monroe County.
  - Omar Koester, crop systems Extension educator, Randolph County, noted that Japanese beetles were common in many local soybean fields and nearby suburban residents also were finding these attractive insects munching on their roses.
  - Shawn Jones, field sales agronomist with Pioneer/DuPont reported on June 25 that moderate numbers of Japanese beetles were showing up in cornfields located near Macon, Maroa, and Mt. Zion (all three communities located in Macon County, Illinois). He also indicated that Japanese beetles could be found on some trees within residential areas of Decatur.
- **Issue No. 15, July 5**—Very high numbers of Japanese beetles were reported in southwestern and east central counties.
  - Very large infestations were reported throughout Macon County, Illinois.
  - Joe Spencer, an entomologist with the Illinois Natural History Survey, reported that Japanese beetle densities were "ramping up at an amazing pace."
- **Issue No. 16, July 12**—Ron Hines, senior research specialist, Dixon Springs Agricultural Center, reported capturing about 600 and 300 beetles per trap per day in two different sites in Pope County. In Massac County, he was capturing nearly 80 Japanese beetles per trap per day.

- John Lilienthal, Pioneer Hi-Bred International, during 1½ days of operation of one Japanese beetle trap in the Kankakee area, he measured 6 gallons of captured beetles.

■ **ISSUE NO. 17, JULY 19**—The "Japanese beetle woes continue."

- "Reports of silk clipping in cornfields and defoliation in soybean fields are common, and insecticide applications to prevent further injury are warranted in many fields."
- "One agronomist estimated that about 10,000 acres of corn and a few thousand acres of soybean had been sprayed in Christian, DeWitt, Macon, and Moultrie counties."

Finally, by late July, densities of Japanese beetles began to wane (not disappear) in corn and soybean fields. It had been a frustrating run with this insect during a hot and dry summer.

How many Illinois counties support infestations of this ravaging insect in their field crops? Joe Spencer (Center for Economic Entomology, Illinois Natural History Survey) and Scott Isard (Department of Geography) used sweep nets to sample soybean fields in each Illinois county during 2002. Results from their exhaustive survey (101 counties sampled) revealed that Japanese beetles could be found in soybean fields in 59 counties (Figure 1). Densities were greatest in east central Illinois (49 beetles per 100 sweeps in Champaign County), ironically, the area of the state infamous for a failed eradication attempt in the mid- to late-1950s by departments of agriculture at federal and state levels.

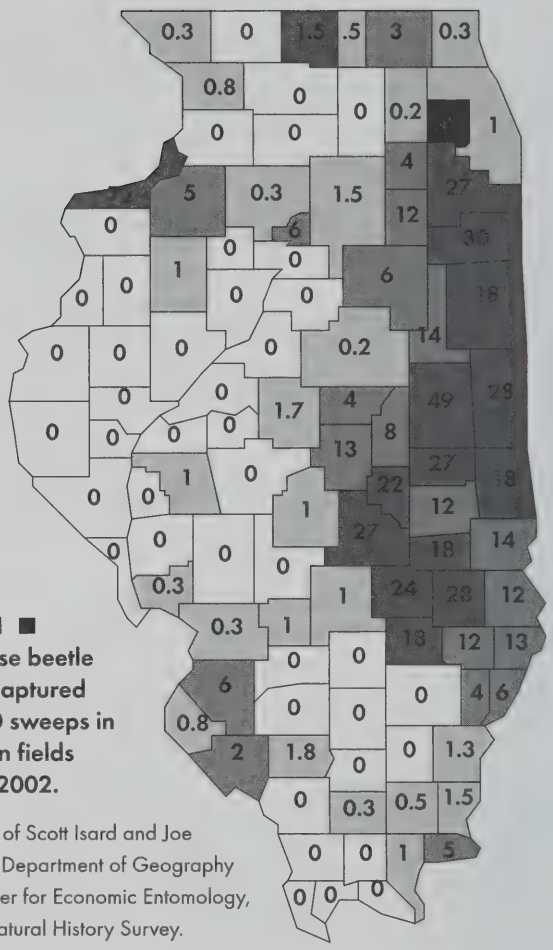



**Figure 1 ■ Japanese beetle adults captured per 100 sweeps in soybean fields during 2002.**

Courtesy of Scott Isard and Joe Spencer, Department of Geography and Center for Economic Entomology, Illinois Natural History Survey.

## ORIGIN AND LIFE CYCLE OF JAPANESE BEETLE

The Japanese beetle, perhaps not surprisingly, is a native insect pest of Japan. It was first reported in southern New Jersey in 1916 and can now be found in all states east of the Mississippi River with the exception of Mississippi and Florida (Edwards 1999). Sporadic infestations also have been observed in a few other states such as California, Iowa, Missouri, and Nebraska. Infestations in California are reported as eradicated. The host range is very large (>250 plant species) (Hammond 1994).

Edwards (1999) described the adults as "shiny metallic green with hard, bronze-colored wing covers. Along each side of the abdomen, just below the wing covers, are six tufts of white hair. The adult is about ½ inch (13 mm) long." The grubs or immatures are approximately 1 inch (25 mm) in length when completely grown and are creamy white with a brown head capsule. The grubs resemble other commonly encountered white grubs in the soil; however, they can be identified by locating a V-shaped pattern of bristles on the ventral (lower) surface of the last abdominal segment (the raster). Japanese beetles have a univoltine life cycle (one generation per year). Female beetles lay their eggs in the soil beginning in mid-June and continue through August. After hatching, larvae complete three instars, feeding on decaying plant material and the roots of grasses. Larvae overwinter in the soil and complete pupation the following spring (mid-to-late May). In early to late June, the attractive adult beetles are often reported for the first time. Luckmann (1959) reported most grubs could be located in the upper 9 inches of the soil and noted that "deep soil freezing" during the winter of 1957–1958 killed many grubs. He further indicated that the females prefer to lay their eggs in corn and soybean fields, with soybean

being the most sought-after location. Egg laying in small grains, forage, and sod was less common.

Japanese beetles cause injury to corn plants by feeding on root hairs as grubs and silks as adults. By feeding on root hairs, the grubs may interfere with efficient uptake of water and nutrients, especially phosphorus. Nutrient deficiencies (phosphorus) in seedling corn plants may result in a purpling of stems. Severely infested fields may have plant stands significantly reduced and warrant replanting. Silk feeding by adults may interfere with pollination, especially in drought years. Hammond (1994) reported that much of the Japanese adult beetle feeding (defoliation) in soybean occurs during the reproductive stages of development. He also indicated that although the grubs may feed on soybean roots, the injury is generally not of economic importance.

## EARLY ERADICATION EFFORTS

Luckmann (1964) offered the following observation about Japanese beetles: "The beetle was found in Illinois in the early 1930s. It has been here ever since, despite efforts to eliminate it, and there is no reason to expect that it will suddenly disappear." He also made the following prediction: " .... it appears that conditions are suitable for the spread, establishment, and build-up of the Japanese beetle. This insect is of considerable economic importance and, unless there is a scientific breakthrough in techniques of eradication, it undoubtedly will become familiar to all of us and probably will become a destructive pest in Illinois." As we know, approximately 40 years after Luckmann's remarks were made at the 16th Illinois' Custom Spray Operators' Training School, Japanese beetles have indeed become very destructive pests in Illinois, in spite of the massive and historic efforts by the United States Department of Agriculture and the Illinois Department of Agriculture in the 1950s to eradicate this insect pest.

During the summer of 1953, Japanese beetles were found near Sheldon, IL (Luckmann 1959). The discovery of these beetles in Iroquois County triggered a massive assault on this insect species in an effort to eradicate it. Approximately 10,000 acres of corn and soybean were infested and eradication efforts were coordinated by state and federal agricultural departments. In the spring of 1954, dieldrin was applied (aerially) at 3 pounds of active ingredient (sprays or granules) per acre to 1,535 heavily infested acres. Dieldrin is a chlorinated hydrocarbon insecticide that belongs to a class of insecticides known as cyclodienes. Dieldrin is one of the most persistent insecticides ever created and may require from 5 to 25 years before 95% of the compound has broken down (Edwards 1966). In 1955, dieldrin granules were applied at a rate of 2 and 3 pounds of active ingredient per acre. The treatments continued. In 1956, 1957, and 1958, dieldrin granules were applied at the rate of 2 pounds of active ingredient per acre. During this eradication effort, roadside ditches also were treated with DDT at a rate of 1 pound of active ingredient per acre. DDT may require 4 to 30 years before 95% of the compound can no longer be detected in the soil (Edwards 1966). By 1958, Japanese beetles could still be found on approximately 50,000 acres of corn and soybean acres near Sheldon, despite that 17,844 acres had been treated with dieldrin. These treatments included the villages of Sheldon and Effner.

Luckmann (1964) reported that Japanese beetles continued to be found from 1958 through 1963 even where insecticides had been applied to suppress beetle densities in the following counties: Coles, Cook, DuPage, Iroquois, Kankakee, LaSalle, Peoria, St. Clair, Tazewell, and Will. In addition, infestations were reported (not treated) in the following counties: Bond, Clark, Edgar, Fayette, Marion, and Wayne. Japanese beetle problems are not unique to farmers. Matzenbacher (1966) reported that this insect pest was first found in Illinois in Chicago and east St. Louis in 1932. However, it wasn't until 1936 that large densities of Japanese beetles were found by urban residents. Matzenbacher (1966) reported the following attempts to manage Japanese beetle infestations in Illinois: "A state Japanese beetle quarantine was promulgated in 1936, and a cooperative control program was inaugurated by the Illinois Department of Agriculture and the United States Department of Agriculture which has been successful in keeping the infestations down to a non-economic level." Matzenbacher (1966) also elaborated on some of the early attempts at biological control efforts for Japanese beetles: "The Departments of Agriculture cooperatively have treated over 180,000 acres of soil in Illinois with chemicals for control of the Japanese beetle, and in 1965 biological control in the form of milky diseases spores was applied to over twenty acres of agricultural land in the East St. Louis area. This was the first time that biological control had been attempted on such a large area." Despite these early management schemes, by the mid-1960s, Japanese beetle populations were well entrenched in

the following Illinois counties: Bond, Clark, Clay, DuPage, Edgar, Fayette, Kankakee, Lake, Macon, Marion, Peoria, Tazewell, Wayne, Whiteside, and Will (Matzenbacher 1966).

## SILENT SPRING

The futile attempt to eradicate the Japanese beetle was discussed at length in the publication of *Silent Spring* by Rachel Carson in 1962. The following passages were taken directly from Chapter 7 (pages 85–100) entitled *Needless Havoc*.

> "Perhaps no community has suffered more for the sake of a beetleless world than Sheldon, in eastern Illinois, and adjacent areas in Iroquois County. In 1954 the United States Department of Agriculture and the Illinois Agriculture Department began a program to eradicate the Japanese beetle along the line of its advance into Illinois, holding out the hope, and indeed, the assurance, that intensive spraying would destroy the populations of the invading insect."
>
> "Although funds for chemical control came in never-ending streams, the biologists of the Illinois Natural History Survey who attempted to measure the damage to wildlife had to operate on a financial shoestring. A mere $1100 was available for the employment of a field assistant in 1954 and no special funds were provided in 1955."
>
> "In spite of the enormous havoc that had been wrought in the name of eradicating the Japanese beetle, the treatment of more than 100,000 acres in Iroquois County over an eight-year period seems to have resulted in only temporary suppression of the insect, which continues its westward movement."
>
> " .... in the eight years of the program, only about $6000 was provided for biological field studies. Meanwhile the federal government had spent about $375,000 for control work and additional thousands had been provided by the state."

The publication of *Silent Spring* alerted the nation to the misuse of insecticides and the consequences of failing to integrate the use of pesticides into an overall balanced IPM program. *Silent Spring* galvanized and strengthened an emerging environmental movement and Rachel Carson became their beacon.

Many of Rachel Carson's statements in Chapter 7 were absolutely correct and were further highlighted by Luckmann (1959) at this conference in January 28–29, 1959. Bill Luckmann is a retired entomologist with the Section of Economic Entomology, Illinois Natural History Survey. Some of Luckmann's observations are provided.

### Observations on insects (Japanese beetles)

> "The treatment applied early each spring killed only about 50 percent of the larvae in the soil at the time of treatment, although large numbers of poisoned grubs would crawl to the surface and die."
>
> "Adult beetles were usually numerous in a treated area during the July and August following treatment. However, larvae hatching from eggs laid during the summer in the treated soil were killed."
>
> "Soil treated in the spring of 1954 with three pounds of dieldrin per acre and repeatedly plowed and cultivated was still free of Japanese beetle grubs in the fall of 1958."

### Observations on farm animals

> "After testing various types of application and making observations for five years, it appears that such livestock as cows, hogs, sheep, and chickens will not be adversely affected when dieldrin is properly applied in granular form at a dosage of three pounds per acre. However, aerial sprays of the same amount of dieldrin or even the drift from the sprays can seriously affect farm animals, particularly sheep."
>
> "Dieldrin residues will occur in the milk of cows feeding on forage treated with 30 pounds of 10 percent dieldrin granules per acre, and the milk will contain dieldrin within a feeding period of 24 hours."

### Observations on wildlife

> "Many game and non-game animals appeared to show an adverse effect soon after the insecticide was applied, but observations later during the five-year period did not indicate that any game or non-game animal had been permanently eliminated from the area."
>
> "Rainfall had varying effects on the numbers of game or non-game animals killed. It appeared that rainwater standing on recently treated land was quite toxic to some birds, whereas heavy rains during the treatment period in 1956 caused few if any deaths among game animals and fish."

Petty (1960), the originator of this conference, amplified the growing concern regarding the issue of milk contamination due to the misuse of dieldrin (or other chlorinated hydrocarbons): "The answer to how to prevent pesticide contamination in milk is simple: use insecticides wisely, not carelessly, and follow recommendations. Apparently, a few dairy farmers are not doing this. Federal and state research agencies and private industry have spent hundreds of thousands of man hours and dollars to establish these recommendations. To ignore them is foolhardy."

## RECOMMENDATIONS AND OUTLOOK FOR 2003

Preventing injury to roots (grubs) and silks (adults) caused by Japanese beetles has proved to be a frustrating experience for many entomologists and producers. Briggs and Kuhlman (1982) indicated that both Counter 15G (2 pounds of active ingredient per acre) and Lorsban 15G (1 pound of active ingredient per acre) provided only an 18% reduction (evaluated on May 26, 1981) in the number of Japanese beetle grubs in an insecticide efficacy trial in Iroquois County. Each product was applied in a 7-inch band over the row and incorporated at planting on May 7, 1981. The following year, Kuhlman and Briggs (1983) reported that infestations of Japanese beetles were very high in east central Illinois during the summer of 1982. They offered the following comments regarding an experiment performed to determine the effect of silk clipping on yield: "Tests conducted during 1982 with no, three, five, and ten beetles caged per ear tip at silk emergence were inconclusive in determining the number required to affect pollination. Ten beetles per ear tip did not reduce ear weight. It should be pointed out, however, that the beetles remained caged on the ear tips for only five days." More work is warranted with respect to improving our economic thresholds for Japanese beetles and also for increasing our understanding of the efficacy for various insecticides that are targeted at the grubs.

Our current economic threshold (Steffey and Gray 2002) for Japanese beetles in corn is as follows: "Treat during the silking period to protect silks if there are 3 or more beetles per ear and pollination is not complete." Edwards (1999) offered some additional recommendations regarding the treatment of corn to prevent silk clipping: "Control with an insecticide may be warranted if silks are clipped to less than ½ in (12 mm), fewer than 50% of the plants have been pollinated, and beetles are feeding." To prevent economic damage in soybean, we (Steffey and Gray 2002) recommend that producers consider a rescue treatment when "defoliation reaches 30% before bloom and 20% between bloom and pod fill."

Successfully predicting the severity of future infestations of Japanese beetles will most likely prove to be a frustrating experience. However, we can offer some general expectations regarding the population fluctuations of this insect. For instance, producers should anticipate economic densities of Japanese beetles after mild winters, followed by early planting (first 2 weeks of April). These infestations will typically be greatest in areas of the state, such as east central Illinois, that have had a history of repeated problems with these beetles.

## WESTERN CORN ROOTWORMS—THE VARIANT CONTINUES ITS SPREAD

The variant western corn rootworm (O'Neal et al. 1999, Levine et al. 2002) continued its expansion in Illinois during the summers of 2001 (Figure 2) and 2002 (Figure 3). Surveys were conducted in late July and early August of each year by Joe Spencer and Scott Isard. They confirmed the presence of western corn rootworm adults in soybean fields in 59 counties. The great densities occurred in east central Illinois, an area with the largest concentration of rotated corn acres. In 2002, western corn rootworms also were common inhabitants of soybean fields in northeastern counties (Lake County). In issue number 23 of the *Pest Management and Crop Development Bulletin*, severe first-year corn rootworm larval damage was reported in Lake County in corn following soybean as well as in corn planted after wheat. Although western corn rootworms were found far less often in soybean fields in western and northwestern counties, 11 adults per 100 sweeps were collected from soybean in Pike County, an ominous early-warning signal that crop rotation may begin to fail as a pest management strategy for this insect species in western Illinois. Similar survey efforts the previous year (Figure 2) revealed only 0.5 adults per 100 sweeps in soybean in Pike County. Farmers, even in western and northwestern counties, are encouraged to use Pherocon AM traps (yellow sticky traps) to monitor their soybean fields for variant western corn rootworm adults. If densities begin to approach

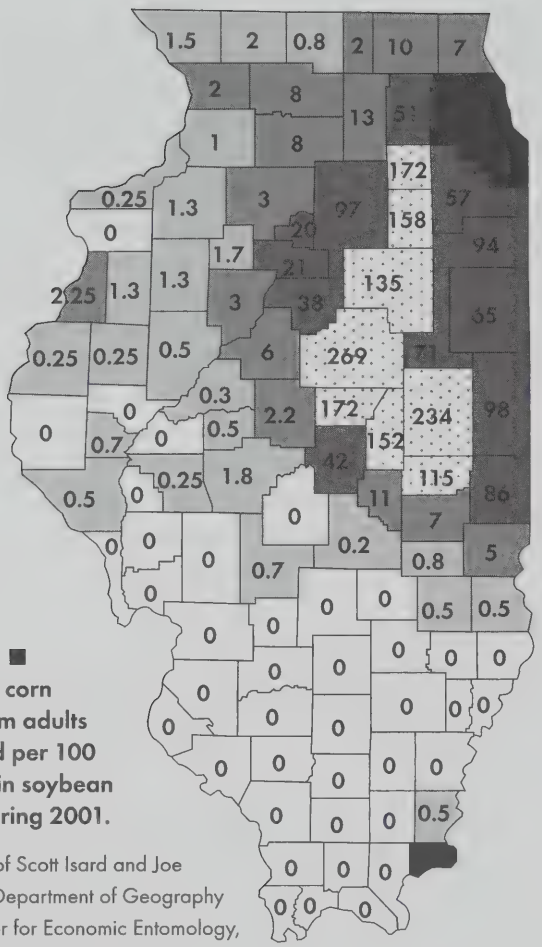



**Figure 2 ■ Western corn rootworm adults captured per 100 sweeps in soybean fields during 2001.**

Courtesy of Scott Isard and Joe Spencer, Department of Geography and Center for Economic Entomology, Illinois Natural History Survey.

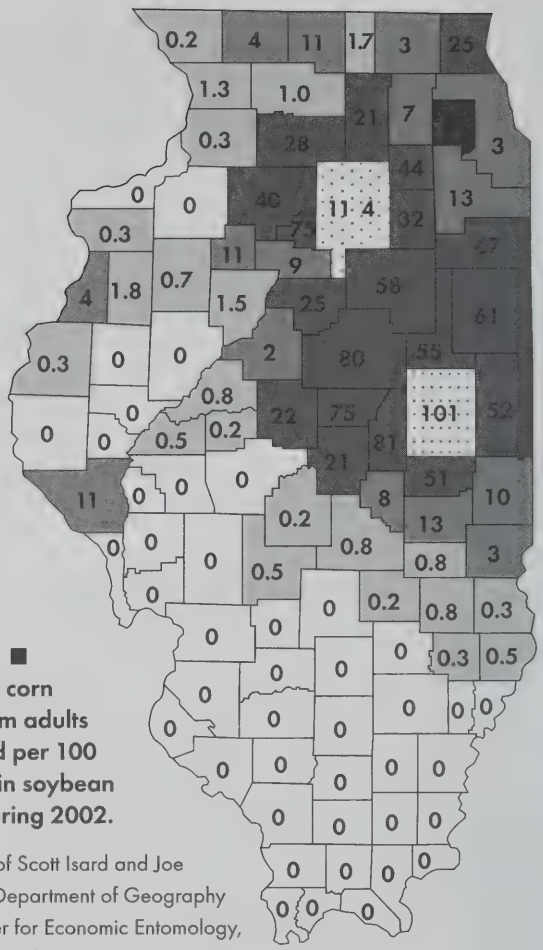



**Figure 3 ■ Western corn rootworm adults captured per 100 sweeps in soybean fields during 2002.**

Courtesy of Scott Isard and Joe Spencer, Department of Geography and Center for Economic Entomology, Illinois Natural History Survey.

five adults per trap per day in soybean fields, producers are encouraged to consider the use of a soil insecticide on rotated corn acres (O'Neal et al. 2001).

In addition to the sweep-net surveys of soybean fields conducted by Scott Isard and Joe Spencer, we initiated an on-farm root injury evaluation of first-year cornfields (following soybean) in August 2002. Our methodologies were similar to those used by Steffey et al. (1992) in their survey of rootworm larval injury in first-year cornfields during the late 1980s. Their study was conducted to determine the incidence of first-year corn rootworm larval damage in fields affected by northern corn rootworms that were able to prolong their diapause. They determined that areas of the state characterized by intensive rotation of corn and soybean had the greatest chance for first-year corn rootworm larval damage caused by northern corn rootworms. In 2002, Jared Schroeder, a graduate student in the Department of Crop Sciences, worked closely with IPM and crop systems extension educators and determined the level of first-year corn rootworm larval injury in 32 Illinois counties. In each county, 10 rotated cornfields were selected at random. In each field, 10 plants were selected at random and the roots were washed and rated for injury on the Iowa State 1 to 6 injury scale (Hills and Peters 1971). Similar to the results of Steffey et al. (1992), the greatest concentration of first-year corn rootworm larval injury occurred in east central Illinois. The percentage of plants with root injury ratings greater than or equal to 3.0 (some root pruning, never equivalent to 1 node) for east central counties was as follows: Champaign, 4%; Ford, 30%; Grundy, 35%; Iroquois, 16%; Kankakee, 11%; LaSalle, 66%; Livingston, 22%; McLean, 53%; Vermilion, 9%; and Will, 20%. The frequency of root injury at or above the economic injury index of 3.0 was less in central Illinois counties: Christian, 0%; Logan, 2%; Macon, 32%; Marshall, 10%; Mason, 2%; Peoria, 2%; Sangamon, 0%; Stark, 0%; Tazewell, 6%; and Woodford, 4%. Two northern Illinois counties, DeKalb and Lee, had 6 and 14%, respectively, of roots with injury ratings at or above 3.0. None of the roots from 10 counties located in the western region of the state had been pruned. These counties included

Adams, Brown, Fulton, Hancock, Knox, McDonough, Mercer, Pike, Schuyler, and Warren. Care must be exercised in the interpretation of these root-rating data. For example, root injury ratings would undoubtedly have been greater in east central Illinois if it were not for the common practice of using soil insecticides on first-year corn. These data also seem to suggest that although western corn rootworm adults are beginning to appear in some soybean fields of western Illinois, egg-laying in these fields is likely below economic levels at this time. Again, we advise producers to use Pherocon AM traps (even in western counties) to make more informed management decisions.

## HISTORICAL EXPANSION OF WESTERN CORN ROOTWORM INTO ILLINOIS

It's interesting to note that the westward expansion of the variant western corn rootworm is now proceeding in the opposite direction from which its precursor first entered Illinois. Petty (1965) announced the arrival of western corn rootworms into Illinois: "Western corn rootworms were found for the first time this past year (1964) in Illinois just south of Rock Island. They were also found along the western border of Wisconsin." The continuing spread of western corn rootworms into Illinois was chronicled in the proceedings of this conference:

- Moore (1966)—five additional counties were infested with western corn rootworms in 1965
- Moore and White (1967)—western corn rootworms were found in four additional counties (Henry, Whiteside, Lee, and Woodford) in 1966, 10 counties in Illinois where western corn rootworms can be found (northwestern sector of Illinois)
- Randell et al. (1968)—extension advisers listed corn rootworm as the insect in which they received the most inquiries, western corn rootworms now present in 20 Illinois counties, "The western corn rootworm is expected to become the primary rootworm problem in at least the northern half of the state within the next few years."
- Kuhlman et al. (1968)—"In total, 6,261,869 acres (a 1 percent increase over 1967) of corn land were treated to protect against soil insects, while 853,338 acres (a 43 percent increase over 1967) were treated for all other insect pests of field crops."
  - corn rootworms were the number one insect in which questions were raised with extension advisers
  - "Resistant western and northern corn rootworms increased and spread, with the result that farmers shifted from chlorinated hydrocarbon corn soil insecticides to the organic phosphates and carbamates."
  - western corn rootworms could be found in 37 Illinois counties
- Kuhlman (1969)—"How many beetles should you find to predict problems next year? We do not know; but 1 per plant is a start, and 3 or more per plant could lead to serious problems."
  - "The highest corn rootworm populations are usually found where continuous corn is grown. The areas with the highest percentage of continuous corn and the highest rootworm populations are in the northwest, northeast, and west districts. The low rootworm populations in the east-central and west-southwest sections closely correlate with the high percentage of fields in first-year corn."
- Kuhlman and Randell (1971)—western corn rootworms found in 47 counties of Illinois (essentially northern ½ of Illinois),
  - "There is a slight trend of displacement of the northern by the western species over the last five years."
- Cooley et al. (1972)—WCR number one insect as reported by extension advisers
  - western corn rootworms have been identified in 54 counties of Illinois
  - "The increase in abundance of the WCR has been one of displacement of the NCR rather than additive since overall combined populations have actually been declining."
- Kuhlman (1973)—corn rootworms number one insect as rated by extension advisers
  - western corn rootworms can now be found in 63 Illinois counties.

Within a 9-year period, western corn rootworms had spread throughout much of Illinois displacing the native northern corn rootworm in many fields as the dominant rootworm species. Since the mid-1990s, we have witnessed the variant western corn rootworm colonizing counties in every direction from its epicenter of Piper City, Ford County, IL. The spread

has been slower to the west and northwest, presumably because of prevailing summer air masses. Will the variant western corn rootworm displace those western corn rootworms that restrict their oviposition to cornfields, similar to the displacement that occurred to northern corn rootworms? Time will tell.

## INSECTICIDE RECOMMENDATIONS FOR WESTERN CORN ROOTWORM

Please refer to an article in these proceedings authored by Kevin Steffey and me on this specific topic. A transition is clearly underway regarding corn rootworm management options that potentially will be available for the first time in 2003 for producers. My thoughts on this topic were offered recently in issue number 13 of the *Pest Management and Crop Development Bulletin.*

> "There is considerable anticipation on the part of producers regarding the potential commercialization of transgenic hybrids for corn rootworm management. In addition, interest in the reliability of seed treatments for rootworm management continues. During the next 5 years, a transition most likely will occur as producers lean more toward seed treatment and transgenic technologies, as the "backbone" of their rootworm management programs. Obviously a lot has to occur before this transition begins to take shape. Most notably, the U.S. EPA will need to approve the use of transgenic hybrids for corn rootworm control. In addition, to date, seed treatments have not shown that they provide consistent root protection against heavy corn rootworm infestations. I think systemic seed treatments have great potential; however, we still have much to learn."

## REFERENCES


Briggs, S.P., and D.E. Kuhlman. 1982. White grub control in corn, pp. 176–179. *In* Proceedings of the 34th Illinois Custom Spray Operators' Training School, University of Illinois, Champaign-Urbana, Illinois.

Carson, R. Needless Havoc. Chapter 7. *In* Silent Spring. The Riverside Press, Cambridge, MA.

Cooley, T.A., D.E. Kuhlman, and R. Randell. 1972. Insect situation, 1971, pp. 51–69. *In* Proceedings of the 24th Illinois Custom Spray Operators' Training School, University of Illinois, Champaign-Urbana, IL.

Edwards, C.A. 1966. Residue Rev. 13: 83.

Edwards, C.R. 1999. Japanese beetle, pp. 90–91. *In* Handbook of Corn Insects. The Entomological Society of America, Lanham, MD.

Hammond, R.B. 1994. Japanese beetle, pp. 64-65. *In* Handbook of Soybean Insect Pests. The Entomological Society of America, Lanham, MD.

Hills, T.M., and D.C. Peters. 1971. A method of evaluating postplant insecticide treatments for control of western corn rootworm larvae. Journal of Economic Entomology 64: 764–765.

Kuhlman, D.E. 1969. Survey of northern and western corn rootworm adult populations, 1968, pp. 108–114. *In* Proceedings of the 21st Illinois Custom Spray Operators' Training School, University of Illinois, Champaign-Urbana, IL.

Kuhlman, D.E., and S.P. Briggs. 1983. The Japanese beetle problem in Illinois, pp. 54–58. *In* Proceedings of the 35th Illinois Custom Spray Operators' Training School, University of Illinois, Champaign-Urbana, IL.

Kuhlman, D.E., and R. Randell. 1971. Insect situation, pp. 66–85. *In* Proceedings of the 23rd Illinois Custom Spray Operators' Training School, University of Illinois, Champaign-Urbana, IL.

Kuhlman, D., S. Sturgeon, and R. Randell. 1969. Insect situation, 1968, pp. 21–32. *In* Proceedings of the 21st Illinois Custom Spray Operators' Training School, University of Illinois, Champaign-Urbana, IL.

Kuhlman, D.E., R. Randell, and T.A. Cooley. 1973. Insect situation and outlook, 1973, pp. 109–126. *In* Proceedings of the 25th Illinois Custom Spray Operators' Training School, University of Illinois, Champaign-Urbana, IL.

Luckmann, W.H. 1959. Summary of Japanese beetle eradication studies, pp. 22–23. *In* Proceedings of the 11th Illinois Custom Spray Operators' Training School, University of Illinois, Champaign-Urbana, IL.

Luckmann, W.H. 1964. The future of the Japanese beetle in Illinois, pp. 51–53. *In* Proceedings of the 16th Illinois Custom Spray Operators' Training School, University of Illinois, Champaign-Urbana, IL.

Matzenbacher, L. 1966. New plant pests, quarantines, and control, pp. 15–19. *In* Proceedings of the 18th Illinois Custom Spray Operators' Training School, University of Illinois, Champaign-Urbana, IL.

Levine, E., J.L. Spencer, S.A. Isard, D.W. Onstad, and M.E. Gray. 2002. Adaptation of the western corn rootworm to crop rotation: evolution of a new strain in response to a management practice. American Entomologist 48: 94–107.

Moore III, S. 1966. Insect situation, pp. 66–69. *In* Proceedings of the 18th Illinois Custom Spray Operators' Training School, University of Illinois, Champaign-Urbana, IL.

Moore III, S., and C.E. White. 1967. Insect situation, 1967, pp. 75–94. *In* Proceedings of the 19th Illinois Custom Spray Operators' Training School, University of Illinois, Champaign-Urbana, IL.

O'Neal, M.E., M.E. Gray, and C.A. Smyth. 1999. Population characteristics of a western corn rootworm (Coleoptera: Chrysomelidae) strain in east-central Illinois corn and soybean fields. Journal of Economic Entomology 92: 1301–1310.

O'Neal, M.E., M.E. Gray, S. Ratcliffe, and K.L. Steffey. 2001. Predicting western corn rootworm (Coleoptera: Chrysomelidae) larval injury to rotated corn with Pherocon AM traps in soybeans. Journal of Economic Entomology 94: 98–105.

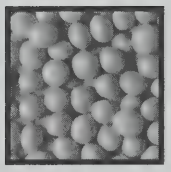
Petty, H.B. 1960. Avoid pesticide contamination of milk, pp. 20–23. *In* Proceedings of the 12th Illinois Custom Spray Operators' Training School, University of Illinois, Champaign-Urbana, IL.

Petty, H.B. 1965. Insect situation, pp. 48–59. *In* Proceedings of the 17th Illinois Custom Spray Operators' Training School, University of Illinois, Champaign-Urbana, IL.

Randell, R., D. Kuhlman, S. Moore III. 1968. Insect situation, 1967, pp. 1–7. *In* Proceedings of the 20th Illinois Custom Spray Operators' Training School, University of Illinois, Champaign-Urbana, IL.

Steffey, K.L., and M.E. Gray. 2002. Insect pest management for field and forage crops, pp. 1–25. *In* Illinois Agricultural Pest Management Handbook, University of Illinois, Champaign-Urbana, IL.

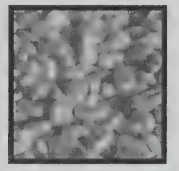
Steffey, K.L., M.E. Gray, and D.E. Kuhlman. 1992. Extent of corn rootworm (Coleoptera: Chrysomelidae) larval damage in corn after soybeans: search for the expression of the prolonged diapause trait in Illinois. Journal of Economic Entomology 85: 268–275.



# PLANT DISEASE ISSUES FROM 2002

**Darin M. Eastburn**

Although the lack of rain through most of June and July limited the levels of foliar diseases this past season, there were a number of diseases that caused significant problems for corn and soybean production in several locations throughout Illinois. Mycotoxins in corn were much more prevalent this season than they have been in the recent past. The warm dry weather, especially in the southern half of the state, lead to an unusually high incidence of ear infection by *Aspergillus flavus*, the fungus that produces aflatoxins. Elevated levels of fumonisins, an other class of mycotoxins, were also detected in corn this season. The warm dry weather favored the development of charcoal rot on corn in the southern sections of the state, while the stalk rot phase of anthracnose was a problem on corn in several northern locations. And even though much of the season was dry, the high levels of rainfall early in the season caused some disease problems in corn as well. Crazy top is a disease of corn that often results from flooding when corn is in the seedling stage, and those farmers that planted corn prior to the early season rains may have experienced significant localized losses because of crazy top. The wet conditions early in the season also caused seedling disease problems on soybeans, and problems with *Phyophthora*, *Pythium*, and *Rhizoctonia* were reported from scattered locations around the state. As with corn, charcoal rot was a problem on soybeans in the southern half of the state this season. The warm dry weather resulted in lower levels of sudden death syndrome (SDS) in many locations, but pockets of severe SDS were seen in areas of western and central Illinois. Some brown stem rot was reported, but we suspect that growers may be mistaking brown stem rot for SDS. Thus, the actual levels of brown stem rot may be higher than we realize. Green-stem was prevalent and problematic in the northern third of the state and somewhat of a nuisance for soybean growers in the central regions.



# WEED MANAGEMENT CHALLENGES FROM 2002

**Aaron G. Hager, Matt Montgomery, and Christy L. Sprague**

## CHALLENGES WITH THE WEATHER

### Cold and Wet

The 2002 growing season marked a year where growers were faced with a variety of weather conditions that made weed management decisions a challenge. The season started in March with fairly favorable conditions for early preplant herbicide applications across a number of acres in Illinois. Most of these applications were soil-applied grass herbicides on corn acres that were meant to be applied anywhere from 14 to 30 days prior to planting. Through most of April and May, rain and cold temperatures kept most of the corn planters in the shed. By the end of April less than 30% of the Illinois corn acreage was planted and cold temperatures allowed for no more than 12% of the crop to emerge. The trend of excessive rainfall and cool temperatures (below 60° F) persisted until the last week of May. This week marked a frenzy of activity that accounted for over 25% of the Illinois corn and soybean acres to be planted in one week. It was the first and third week of June before over 90% of the corn and soybean acres were planted, respectively.

One of the first challenges that growers faced was the reduced activity of some of the soil-applied grass herbicides that had been applied in March and early-April. The heavy rainfall that plagued much of the state moved these herbicides deeper into the soil profile than was conducive for good weed control. Some of the work conducted by Bunting and Simmons (unpublished) at the University of Illinois has shown that with 2.5 inches of rainfall, as much as 50% of an applied herbicide can leach out of the top 2.5 inches of the soil profile (depending on herbicide) and with 10 inches of rainfall, anywhere from 35 to 70% will remain in the top 5 inches. Rainfall amounts in excess of 10 inches were not uncommon throughout many parts of the state in April and May. Movement of these herbicides below the weed seed germination zone often times leads to lack of control and late-season weed escapes. In addition, the excess moisture can lead to hydrolysis or breakdown of some of these products.

Excessive precipitation was not the only factor that affected herbicide performance in April and May. Cool to cold temperatures, particularly in mid-May, had an effect on postemergence herbicide performance. Corn that was planted in mid-April was growing in conditions were average daily air temperatures cycled anywhere from 40 to 70° F. This earlier planted corn was ready for postemergence herbicide applications by the third week of May. Some of these postemergence herbicide applications were to frost-damaged corn that was growing when average daily temperatures were below 50° F. Herbicide applications that occurred under these stressful conditions often times resulted in reduced weed control and increased crop sensitivity. For example, postemergence applications of Callisto (mesotrione) under cold temperatures increased corn sensitivity and resulted in bleached corn leaves. These plants were able to recover when temperatures increased and the plant was able to metabolize the herbicide. Warnings about postemergence herbicide applications under cool temperatures are on a number of labels. For example, the Raptor (imazamox) label cautions against postemergence applications when temperatures are below 50° F for more than 10 hours.

Under these conditions soybean plants are not actively growing and aren't able to effectively metabolize the herbicide, causing an increase in soybean injury. Postemergence herbicides should not be applied during periods of cold temperatures and crops should be allowed to recover from these stressful conditions before making a postemergence herbicide application.

The early-season cool conditions, also left the corn crop at several different stages at the time of postemergence herbicide applications this year. This phenomenon became extremely critical when these applications were approaching the maximum corn size window for certain herbicides. Most herbicide labels often refer to plant height, growth stage, or both when discussing timing of postemergence applications. On labels where both crop height and growth stage are mentioned, it is important to follow the more restrictive of the two. During the cool conditions that we experienced early in the season corn stays relatively small in regards to plant height. However, corn continues to advance developmentally. For example, the Accent label indicates that applications can be made to corn up to 20 inches tall or that has 6 or fewer collars (V6), whichever is more restrictive. If the herbicide application was made by only looking at corn height, there is a possibility that corn injury could occur because the application was made to corn beyond the labeled growth stage. Following the more restrictive of the two is extremely critical especially under cool growing conditions.

### Hot and Dry

In contrast to the cold and wet conditions growers faced early in the season, hot and dry conditions were more prevalent throughout many areas of Illinois in June, July and August. Weeds, such as common lambsquarters and common waterhemp, were tougher to control with many of the postemergence herbicides under these conditions. Decreased control of these species is often related to decreased herbicide absorption into the plant. Under hot and dry conditions many weed species form thicker leaf cuticles that act as barriers to herbicide absorption. Herbicide additive selection can sometimes enhance weed control under these conditions. For many products a non-ionic surfactant (NIS) may be the additive of choice, however many labels may allow for the use of a crop-oil concentrate (COC) under very dry conditions to enhance weed control. However, keep in mind that using a COC instead of a NIS increases the potential for crop injury for several postemergence herbicides.

Dry conditions this year not only affected the 2002 season, but may also impact rotational crops in 2003 due to persistence of herbicide residues in the soil. There are several corn and soybean herbicides that have the potential to carryover into rotational crops after a dry season. Rotational restrictions for many of these herbicides can be found in the *Illinois Agronomy Handbook, Illinois Agricultural Pest Management Handbook,* or on the herbicide label. Some of the factors that need to be considered to determine if carryover may be a problem in 2003 are: 1) the herbicide's ability to persist in the soil, 2) the amount of rainfall or soil moisture available for degradation, 3) soil temperature, and 4) soil pH.

Soil moisture is the most limiting factor for the degradation of herbicides this season. Dry soil conditions generally reduce the rate of herbicide degradation. Soil moisture is extremely important, especially in the first 2 to 4 weeks after application. If rainfall and soil moisture were not sufficient during this time, dissipation of the herbicide was likely reduced, increasing the potential for carryover. Additionally, lack of soil moisture can result in increased herbicide adsorption to soil particles and organic matter, reducing herbicide availability for degradation. Herbicide labels that include minimum precipitation requirements include *imazaquin*-containing products (Backdraft, Scepter, Squadron and Steel), *prosulfuron*-containing products (Exceed, Spirit and Peak), and *clopyralid*-containing products (Stinger, Hornet and Accent Gold). Other herbicides affected by low soil moisture include Command, Pursuit and Lightning.

Due to the planting delays this season, time of herbicide application may also influence rotational crop injury concerns. There were several late-season "rescue" applications made this year, so be sure to observe the rotational crop interval on the respective herbicide labels for these late-season applications before planting rotational crops.

## LATE WEED FLUSHES

Another challenge that dry soil conditions presented this year was the lack of rapid soybean canopy closure, especially when soybeans were planted in wider (30 inch) row spacings. In many fields, an

additional flush of weeds emerged following the initial postemergence herbicide application due to the delay in soybean canopy development and the lack of soil residual activity from many postemergence herbicides. Two species in particular, morningglory and hophornbeam copperleaf, we frequently observed emerging after the initial postemergence application.

There are several soil-applied soybean herbicides that can provide some residual control of these species. With respect to hophornbeam copperleaf, Authority, Valor, FirstRate/Amplify, and Sencor each can provide several weeks of residual control. Authority, Canopy, Canopy XL, and FirstRate/Amplify are soil-applied herbicide options that can provide residual control of morningglory. While these products may not provide sufficient, season-long control of these species, they may allow the initial postemergence application to be delayed (perhaps 10 days to 2 weeks) until later during the season. FirstRate/Amplify can be tank-mixed with several other postemergence soybean herbicides and may provide some residual control of these species.

It is difficult to predict the growing conditions that will be encountered in 2003; perhaps conditions will be more conducive for a more rapid soybean canopy development that will help suppress weeds that emerge following a postemergence herbicide application. Keep in mind, however, that the weed spectrum encountered in many Illinois corn and soybean fields is such that a single postemergence herbicide application may not always provide an acceptable level of weed control, even under better growing conditions.

## PPO INHIBITOR-RESISTANT WATERHEMP IN ILLINOIS

At the 2002 Illinois Crop Protection Technology Conference, Dr. Dallas Peterson of Kansas State University reported on work conducted by KSU researchers on a PPO-resistant waterhemp biotype identified in Kansas. At the 2003 Illinois Crop Protection Technology Conference, we report that the phenomena of PPO resistance is no longer confined to the Kansas waterhemp biotype. At least one (and most likely several more) waterhemp population in Illinois is now confirmed to be resistant to PPO inhibitors. This population is located in western Illinois, but we have received other anecdotal reports of PPO inhibitors (i.e.,diphenylether herbicides) failing to control waterhemp. Not all of these reports have emanated from western Illinois however, and we are concerned that PPO inhibitor-resistance in Illinois waterhemp populations may be more widespread than initially perceived.

Before going any further, let's also say it is unlikely that every instance of PPO inhibitors failing to provide complete control of waterhemp is attributable to resistance. Less than complete control of waterhemp with PPO-inhibiting herbicides is not something that was unique to the 2002 growing season. For many years, we (and many others for that matter) have observed waterhemp control range from complete to much less than satisfactory with these herbicides. Regrowth of susceptible waterhemp plants tends to happen more frequently when postemergence applications are made to plants larger than 5 inches in height and/or under adverse growing conditions (primarily extended periods of dry soils). Late-season applications of these herbicides, usually made when waterhemp plants are very large and nearing the reproductive stage, also can result in poor control. Please note that instances of poor waterhemp control such as these are NOT necessarily attributable to herbicide resistance.

In 2002, we initiated field experiments on the producer's field in western Illinois to determine the resistance characteristics of the waterhemp biotype. Each experiment (soil-applied and postemergence) included several PPO-inhibiting herbicides as well as herbicides with other sites of action. No crop was planted in the study area due to adverse weather conditions. The soil-applied experiment was evaluated 30 days after application, while the postemergence experiment was evaluated 7 and 21 days after application.

Results from the soil-applied experiment indicated all herbicides, other than ALS inhibitors, provided excellent waterhemp control 30 days after application. Soil applications of Authority, Valor, and Flexstar (all PPO inhibitors) provided 86 to 99 percent waterhemp control. Soil applications of Pursuit, Classic, and FirstRate did not provide any waterhemp control compared with a nontreated check. The fact that soil-applied PPO inhibitors controlled the waterhemp biotype was not terribly surprising given that Kansas State University researchers also have reported good control of the Kansas PPO-resistant waterhemp biotype with soil-applied PPO inhibitors.

Results from the postemergence experiment indicated all ALS inhibitors did not provide any waterhemp control, and that control with PPO inhibitors ranged from 13 to 53 percent. The PPO inhibitors were each applied at four rates, representing a ½x, 1, 1.5, and 2x rate. The 2x rates of Cobra, Flexstar, Ultra Blazer, and Aim provided only 28, 46, 53, and 23 percent waterhemp control, respectively, 21 days after application. These results are similar to those reported by the Kansas State University researchers.

We are currently conducting additional experiments (greenhouse and laboratory) with this waterhemp biotype. In particular, Dr. Patrick Tranel and his graduate student William Patzoldt are attempting to determine the resistance mechanism and how the resistance trait is inherited.

## INSECT-WEED INTERACTIONS IN 2002

The 2002 growing season presented some "interesting" weed management challenges to growers around the state. In various fields weeds such as giant ragweed, Pennsylvania smartweed, horseweed (marestail), common lambsquarters, and common waterhemp were not effectively controlled by glyphosate. In many cases, the tops of these plants would become necrotic, but the lower portions appeared uninjured and rapidly produced new growth. Splitting the stems of these weeds revealed tunneling throughout the vascular tissue that ranged anywhere from a ¼ inch wide to 90% loss of the conductive tissue.

The culprit in many of these fields with "poor control" was not herbicide resistance or poor herbicide performance, but insects feeding within the stems of these plants. This tunneling throughout the stems appeared to compromise herbicide effectiveness. Since glyphosate is a translocated herbicide, insect injury to the vascular tissue may have reduced its translocation throughout the plant, compromising herbicide performance.

### Stem Boring Insects

Several different insects were found in giant ragweed, Pennsylvania smartweed, horseweed (marestail), common lambsquarters, and common waterhemp in 2002. Of these insects, three species appeared most frequently in fields that experienced reduced weed control from glyphosate.

The first insect species found was common stalk borer larvae, *Papaipema nebris*, in giant ragweed plants. This year was not the first year common stalk borer has reduced herbicide activity on giant ragweed; however it seems to have appeared on a larger scale this year. Common stalk borer larvae hatch from overwintering eggs in the spring and immediately burrow into available host plants (Ratcliffe et al. 2001). Over one hundred plant species may serve as suitable hosts for common stalk borer larvae (Wright et al. 2000). These larvae continue feeding in the host plant until they are fully mature, until the girth of available stem material becomes too small, or until host plants are killed. As larvae outgrow their initial host plants, they migrate to nearby larger-stemmed host plants, usually in June. After they finish feeding, the larvae pupate, and moths emerge in late summer and early fall. Eggs are then deposited on weed hosts and overwinter (Ratcliffe et al. 2001). Common stalk borer have one generation per year and acceptable weed hosts include common burdock, curly dock, pigweed species, grass species, and giant ragweed (Steffey 2002).

Another insect observed tunneling in several weed species is yet to be identified to the level of species. Both larvae and adults of this insect were observed feeding in weed stems in 2002. In October of 2002, John Bouseman of the Illinois Natural History Survey identified the larvae as belonging to the genus *Lixus*. The larvae were legless white grubs with orange heads, and the adults were slender brown weevils. The larvae and adults could both be found within weeds that had small diameter stems. Some *Lixus* species are noted for their stem feeding habits on weeds in the *Polygonaceae* family (Medland and Fewless 2002) and the *Amaranthaceae* family (Vrablova et al. 1997).

The third insect species found tunneling in weed stems was tentatively identified as Dectes stem borer (soybean stem borer), *Dectes texanus*. The Dectes stem borer larvae are approximately 1-inch long with an orange-red head capsule and a white-colored body. These lavae were found in stems of various weed species. Adult Dectes stem borers are gray in color with very long antennae and have somewhat flattened bodies. Within a week of emergence, female Dectes stem borers mate and begin depositing eggs the following week in petioles. When the insect reaches the fourth instar (late summer-early fall) it

tunnels to the base of the host plant (i.e., giant ragweed and cocklebur) (NCAES). Tunneling may be so severe that the plant lodges.

### Implications of Insect–Weed Interactions

The effectiveness of certain translocated herbicides was compromised this year in certain areas due to insect-infested weeds. Although this has happened in the past, this year it seemed to be on a much larger scale. These interactions raise a number of questions on the how we will approach postemergence herbicide applications in the future: 1) Will we continue to see these insect-weed interactions occurring that reduce effectiveness of translocated postemergence herbicides? 2) If these interactions occur what are the implications of not controlling these insect infested weeds? 3) What may be some of the approaches to control these insect-infested weeds?

At this time we don't know if these interactions were rare occurrences in 2002, or if they will continue to be a problem in the future. Implications of not controlling these weeds on a larger scale may relate to competition for yield and future weed problems due to seed production. For example, *Lixus* species such as *L. cardui* have been reported to reduce plant vigor and size, but not seed production (Woodburn and Briese 1996). While glyphosate continues to be a convenient, efficacious, and economical herbicide program, it seems that most of the insect infested weed escapes occurred on larger plants. If these weeds are targeted for applications at smaller stages they may be more easily controlled and less attractive to stem boring insects. There are still a lot of questions and unknown answers related to these insect-weed interactions that need to be examined further.

## REFERENCES


Medland V., and G. Fewless. 2002. Cofrin Arboretum Center for Biodiversity: Photo of the Week: Week of July 14, 2002. Biodiversity Center Home: Photo Archives: Week of July 14, 2002. University of Wisconsin–Green Bay. Green Bay, WI. Available at http://www.uwgb.edu (posted July 2002; verified September 2002).

NCAES. Soybean Stem Borer. North Carolina IPM Network. North Carolina State University. Raleigh, NC. Available at http://ipmwww.ncsu.edu (verified September 2002).

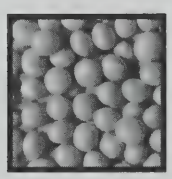
Ratcliffe, S.T., Gray, M.E., and K.L. Steffey. Common Stalk Borer: *Papaipema nebris*. Insect Information. No. 21. Available at http://www.ipm.uiuc.edu (posted 2001; verified September 2002).

Steffey K. 2002. Stalk Borers Could Be Moving Into Cornfields in Some Areas. Pest Management & Crop Development Bulletin: May 24, 2002. Vol. 2002, No. 09. pp. 98.

Woodburn, T.L., and D.T. Briese. 1996. The Contribution of Biological Control to the Management of Thistles. Thistle Management. pp. 250. (Reprinted from *Plant Protection Quarterly*. Vol.11, Supplement 2 1996).

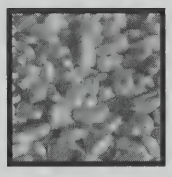
Wright, R.J., Hunt, T., and K. Jarvi. 2000. Common Stalk Borer in Corn. NebGuide. University of Nebraska. Lincoln, NE. Available at http://www/ianr.unl.edu (posted April 2000, verified September 2002).

Vrablova, M., Toth, P., and Cagan, L. 1997. *Lixus species* (Coleoptera: Curculionidae) damaging *Amaranthus* plants in Slovakia. Biological Control of Weeds. pp. 22 (poster).



# CROP MANAGEMENT ISSUES FROM 2002

**Emerson Nafziger**



# DISEASE INTERACTIONS: SCN, SDS, AND BSR: WHAT'S GOING ON HERE?

**Terry Niblack and Dean Malvick**

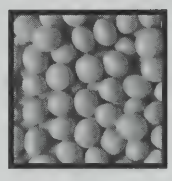
The soybean cyst nematode (SCN) does more than reduce soybean yields by hijacking soybean physiology. SCN is also one of the partners involved in the development and spread of sudden death syndrome (SDS), and recent research suggests that SCN is involved in brown stem rot (BSR) of soybean. That's bad news for Illinois farmers, considering that SCN occurs in more than 80% of Illinois soybean fields.

SDS has rapidly emerged in the past few years as a major threat to soybean production in Illinois. SDS has few equals in its ability to rapidly and completely devastate a soybean field. The fungus that causes SDS (*Fusarium solani* f.sp. *glycines*) is fully capable of acting on its own, but research in the past decade has shown that SCN hastens the development of SDS symptoms and increases their severity, leading to greater yield loss. The fungus, on the other hand, can infect SCN eggs!

BSR, caused by the fungus *Phialophora gregata*, is an "old" threat to soybean production, but recent observations suggest that it's becoming more widespread and severe than in the past. An interaction between the fungus and SCN that affects BSR development was not considered likely until very recently, when researchers at Iowa State University found that infection by SCN can actually break resistance to BSR. Currently, no one knows what effect the fungus has on SCN.

In addition, BSR may be moving further south, just as SDS is moving further north. The old guideline that BSR is only a northern problem and SDS is only a southern problem, is showing signs of breaking down. Worst of all, is it possible for all three pathogens to interact in the same field? Researchers and extension educators in Illinois have formed collaborations focused on the problems posed by these soybean disease interactions. In the laboratory, greenhouse, and the field at a number of locations, we are studying the interactions between SCN and the fungi involved in SDS and BSR.

All three diseases can be controlled by resistance. Do you know how to tell them apart? We'll address the conditions that favor these diseases as well as symptoms and diagnosis. Knowing how to identify these diseases is critical to successful management. If you have to make a choice, is it more important to choose a cultivar resistant to the nematode or the fungus? We'll let you know.



# STRESS AND THE COMMON CORN PLANT

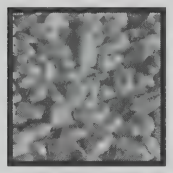
**Bob Nielsen**

Once planted, the crop's yield potential is influenced by an array of biotic and abiotic stresses. Stress affects corn yield both directly and indirectly. Similar stresses occurring at different developmental stages cause very different crop damage. The critical times for stress effects in corn can be described in terms of the stand establishment phase, the rapid growth phase, the pollination phase, and the grain filling phase.

The stand establishment phase occurs from the time the seed is planted until the plants are roughly knee-high or approximately leaf stage V6 (six visible leaf collars). Success at this stage depends both on the success of emergence and the initial nodal root development from approximately the two-leaf to six-leaf stages of development.

After the stand establishment phase, the corn plant shifts from vegetative to reproductive modes and enters what is termed the rapid or "grand" growth phase. Overall plant growth accelerates during this period and nutrient uptake skyrockets. Severe stresses during the rapid growth phase can greatly limit the size of the "factory."

The critical pollination phase includes tassel/silk emergence and pollen shed. Severe stress during this period can have the greatest yield effects per day of stress. The grain filling phase occurs from the end of pollination until the kernels become physiologically mature with visible kernel black layers. Yield losses during this phase result from stand losses, kernel abortion, lightweight kernels, and premature plant death. Once kernels are physiologically mature, they are safe from further effects of physiological stress.



# MANAGING BIRDS, DEER, AND SMALL RODENTS IN THE FIELD

**Ron Hines and John Pickle**

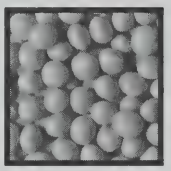
Some of the most common pests of field crops in Illinois include birds, deer, and small rodents. Although most small rodents primarily cause stand reduction problems in conservation tillage-produced crops, birds and deer can cause plant stand reduction in any tillage situation. Regardless of the pest, a combination of research-proven integrated pest management (IPM) practices can assist in the reduction of field crop damage.

Although birds may cause damage to the ends of ears of corn late in the season, the primary damage caused by birds to planted corn is plant stand reduction at or shortly after planting. Corn is most susceptible to bird injury by the digging of kernels or pulling of sprouting corn until it reaches approximately 4 inches in height. In taller corn, the planted kernel has deteriorated sufficiently to no longer be attractive as a food source for birds. The most common group of birds to cause plant stand reduction in corn are the blackbirds. The primary blackbirds include the red-winged blackbird (*Agelaius phoeniceus*) and the common grackle (*Quiscalus quiscula*). In recent years, the population increase of the American crow (*Corous brachyrhynchos*) has placed it into a similar damage potential stature. Understanding feeding preferences, nesting habits, available damage control techniques, and federal laws that protect migratory birds is the best approach to the development of an IPM program that can minimize crop damage from birds.

In Illinois, the white-tailed deer (*Odocoileus virginianus*) can be a serious pest in corn and soybean. Although the most significant damage to corn occurs from pollination through harvest, plant top depredation before V6 seems to be the most damaging to soybean yields. The ample use of available deer harvest seasons combined with area habitat modification, exclusion, and various cultural control methods can all be effective damage control techniques. The best approach depends on the value of the crops to be produced and the landowners desire for damage management. Resent research gives some answers.

Small rodent damage is the primary cause for plant stand reduction in no-till crop production in Illinois. Conservation tillage corn from planting until it reaches 8 to 12 inches in height may suffer damage from small rodents. The three major small rodent pests in Illinois are the prairie vole (*Microtus ochrogaster*), meadow vole (*Microtus pennsylvanicus*), and thirteen-lined ground squirrel (*Spermophilus tridecemlineatus*). Each rodent has a specific associated habitat and geographical distribution pattern. Voles and ground squirrels can damage an entire field, or only a portion. Knowing the proper field scouting techniques, and the rodent's biology, habitat requirements, and food preferences are keys to successful small rodent damage prevention in field crops. Recent research results on various damage control techniques, including toxicants and application equipment, helps determine the best damage control approach.

Handouts that include results from some of the most recent Illinois research on damage control of these field crop pests are available to those who attend this session.



# GETTING IT RIGHT THE FIRST TIME: CALIBRATING FIELD SPRAYERS

**Mark F. Mohr and Robert E. Wolf**

Accurate calibration is the only way to know how much chemical is applied. Even with the current widespread use of electronics to monitor and control the application of crop protection products, a thorough sprayer calibration procedure is essential to ensure against misapplication. Failure to calibrate a sprayer can injure crops, cause pollution, and waste money.

There are many methods for calibrating low-pressure sprayers, but they all involve the use of the variables in the equation below. The three variables listed affect the amount of spray material applied per acre: 1) the nozzle flow rate, 2) the ground speed of the sprayer, and 3) the width sprayed per nozzle. To calibrate and operate a sprayer properly, you must understand how each of these variables affects sprayer output.

Calibration using the equation below has four advantages. First, it allows you to select the number of gallons to apply per acre and to complete most of the calibration before going to the field. Second, it provides a simple means for frequently adjusting the calibration to compensate for changes due to nozzle wear. Third, it can be used for broadcast, band, directed, and row crop spraying if the applicator has a thorough knowledge of nozzle types, sizes, and the recommended operating pressure ranges for each relevant type of nozzle. Finally, when using the method below the applicator has a better understanding of how each variable affects the application rate. As each of the variables changes, the influence on the nozzle flow rate (gallons per minute) is apparent.

The gallons per minute of spray per nozzle can be determined by using the following equation:

(Equation 2) $$GPM = \frac{GPA \times MPH \times W}{5{,}940}$$

GPM = gallons per minute of output required from each nozzle

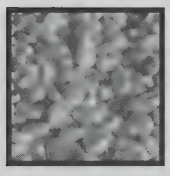
GPA = gallons per acre

MPH = miles per hour

W = inches sprayed per nozzle

5,940 is a constant to convert gallons per minute, miles per hour, and inches to gallons per acre.

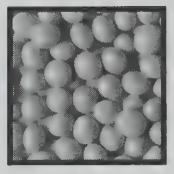
Thus, the size of the nozzle tip depends on the application rate (GPA), ground speed (MPH), and effective width sprayed (W) used.



# TRANSMISSION OF BEAN POD MOTTLE VIRUS IN SOYBEANS BY BEAN LEAF BEETLES AND WESTERN CORN ROOTWORM ADULTS

**Eli Levine, Timothy R. Mabry, Scott A. Isard, Joseph L. Spencer, Houston A. Hobbs, Glen L. Hartman, Leslie L. Domier, Wayne L. Pedersen, and Todd A. Steinlage**

Bean pod mottle virus (BPMV) is a beetle-transmitted viral disease of soybean. The disease causes a mottling of soybean leaves and severe strains of the virus may cause puckering and distortion of the leaves in the upper canopy. Stems of infected plants may remain green after the pods have matured and plants also may retain the leaf petioles after the leaf blades have abscised (green stem). In addition to causing harvesting problems, BPMV can lower seed quality and yield. The primary vector of BPMV is the bean leaf beetle. The western corn rootworm is now found in very high numbers in soybean fields in east central Illinois and northern Indiana. In addition to laying eggs in these fields, adults also feed on soybean foliage. In 1999, we discovered that some of the adult western corn rootworms collected in Illinois soybean fields tested positive for BPMV. Because western corn rootworms are highly mobile and frequently fly among fields, a more widespread distribution of BPMV could occur. In laboratory cage studies, we demonstrated BPMV transmission by using field-collected western corn rootworms. Our results suggest that transmission efficiency is lower for western corn rootworms than for bean leaf beetles. In soybean field sampling trips, 20 of 21 Illinois counties had western corn rootworms that tested positive for BPMV in 2000. In 2001, western corn rootworms tested positive for BPMV in 20 of 23 counties. The percentage of beetles testing positive for the virus ranged as high as 95% in some counties.



# POLLEN DRIFT AND ITS IMPACT ON GENE FLOW BETWEEN GM AND NON-GM CULTIVARS

**Martin Bohn**

## INTRODUCTION

In natural populations, formation of a new generation is a random process. During meiosis, genetic information is randomly distributed to form haploid male (pollen) and female gametes and the drawing of male and female gametes to form the next generation is a result of chance. In contrast, plant breeders control this random process by producing homozygote lines. All gametes produced by these lines are genetically identical, allowing the production of breeding populations with a defined genetic composition. In contrast to the breeding process, the movement of pollen and the genetic information it contains within and among crop production fields cannot be controlled.

Population geneticists investigated gene flow among natural populations caused by pollen dispersal and its consequences on population structure. Plant breeders studied the dispersion characteristics of pollen to determine isolation distances for seed production. However, with the increased availability and use of genetically modified (GM) cultivars and the rising public concerns about possible problems put pollen dispersal and the resulting gene flow into a new perspective.

## GENE FLOW: ECONOMIC EFFECTS

The production of non-GM corn and soybean, i.e., cultivars that were not genetically modified, is viewed by many farmers as a source of additional income. The production for this specialty market increased from 50,000 acres in 1998 to 640,000 acres in Illinois in 2000 (Swanson et al., 2001). In a farm survey conducted by the American Corn Growers Association (see http://www.acga.org, confirmed October 18, 2002) in 2001, 78% of the interviewed farmers stated that they were willing to plant non-GM cultivars to keep customers satisfied and to keep world markets open for U.S. corn. However, the farmer will receive a premium only after biochemical tests are unable to detect transgenes in the product, e.g., genes transferring insect resistance or herbicide tolerance. These analytical kits are highly sensitive and allow the detection of transgenes at low concentrations.

Furthermore, the genetic information carried by pollen is intellectual property owned by companies that developed the cultivar and the specific transgene. Therefore, it is also in the interest of breeding companies to contain pollen drift among fields by suitable measures to avoid misuse of their inventions and breeding germplasm. In addition, farmers who deliberately or nondeliberately use the seed contaminated by pollen drift may be accused of passively infringing patent laws, although this use is in contrast to the notion that seeds or pollen blown onto a farmer's land would normally be considered their property. A Canadian court already ruled that this was not the case with patented GM plants (see http://www.cropchoice.com/leadstry.asp?recid=274, confirmed 10-18-2002).

## GENE FLOW: ECOLOGICAL EFFECTS

Maize was domesticated in Mexico, where a large number of maize landraces are grown among its wild

relative teosinte, representing a sizable pool of genetic diversity, a key prerequisite for a future continuous plant improvement. It is a major concern that a potential gene flow from genetically modified maize hybrids into landraces and natural populations of wild relatives may cause genetic erosion and increased weediness of maize and teosinte carrying a specific transgene (Rodgers and Parkes 1995). Also, in oilseed rape (*Brassica napus*) production, another crop species targeted for improvement by genetic modification transferring genes for improved quality and herbicide tolerance, interspecific crosses between oilseed rape and other *Brassica* species were observed. The introduction of transgenes into weedy *Brassica* populations is, therefore, probable. However, only scanty information is available on the change of fitness caused by transgenes in weedy wild *Brassica* populations (Hauser et al. 1997, 1998).

Seed and pollen are transport vectors of transgene introgression into non-GM crops causing economic difficulties, whereas pollen is the only source of transferring genes from genetic modified organisms (GMOs) into genetic resources, such as landraces, causing potential ecological problems. Seed carrying a transgene can be mixed with non-GM grains during planting, harvest, storage, and transport operations. In addition, it was reported that the transgene was present in conventional non-GM seed lots for planting, making a GMO-free crop production impossible (Jemison and Vayda, 2001). An adjustment of technical farm procedures can be used to avoid mixing of GM and non-GM seed, e.g., planting and harvesting conventional crops before GM crops. However, a containment of pollen employing normal farming procedures is not possible.

## POLLEN DRIFT

Pollen drift depends on the plant specie's reproduction system, the physical characteristics and properties of the pollen, the amount and longevity of the pollen, and meteorological parameters.

### Reproduction biology

Maize is an outcrossing species, i.e., pollen is released into the atmosphere and carried by wind and turbulences to other plants. Other crop species, e.g., oilseed rape, have similar reproduction biology but depend on insects for cross-pollination. In contrast, species such as soybean and wheat are self-fertilizing crops, i.e., the pollen is contained in the closed flower and not released to the atmosphere. Therefore, pollen drift is of less concern in non-GM soybean production. Due to its high economic importance, I concentrate my discussion of pollen drift and its consequences on maize.

### Physical characteristics

Maize pollen is 90 to 100 μ in diameter and has a spherical shape. Pollen of other species that depend on wind pollination, such as ragweed species (*Ambrosia* ssp.) or timothy (*Phleum pretens*) is 3 to 4 times smaller. Maize pollen compares in size to the largest particles commonly airborne (Raynor et al. 1972). Therefore, drift of maize pollen is mainly influenced by its large size. Maize pollen is not transported as far as smaller pollen by wind and it settles quickly (0.3m $s^{-1}$; Di-Gionvanni et al. 1995).

### Amount and longevity of pollen

Maize pollen may remain viable for 24 h (Purseglove 1972), but viability decreases sharply with desiccation (Buitink et al. 1996). At anthesis, 60% of the pollen fresh weight is comprised of water. If water content drops below 40%, longevity is markedly reduced.

### Meteorological parameters

Wind speed and direction as well as turbulences determine horizontal and vertical dispersion of pollen (Di-Giovanni and Kevan 1991). Atmospheric humidity and temperature influence pollen longevity.

## EXPERIMENTAL RESULTS

Several studies using different methods were conducted in the past 50 years to determine the relative importance of the above-mentioned factors on pollen drift and to test the usefulness of pollen control measures. Raynor et al. (1972) used wind impact samplers to determine the pollen concentration at different distances from the pollen source. They noted that at 60 m from the pollen source in the main wind direction, pollen concentrations averaged 1% of those at 1-m distance from the source. Jones and Newell (1948) determined a remaining pollen concentration of 1% at 427 m in the atmosphere. Based on these results and the assumption that each plant produces on average 25 million pollen grains, it can be calculated that approximately 125,000 pollen grains remain at a distance of 500 m (Emberlin et al. 1999). This pollen is potentially available for fertiliza-

tion. However, the number of successful fertilizations depends on the amount of viable pollen, pollen competition from other sources, and the success to land on a receptive stigma (Treu and Emberlin 2000).

To obtain a direct measure of successful cross-pollinations, a cultivar with a dominant trait that can be observed easily, e.g., a color marker or herbicide tolerance, can be used as a pollen source (donor), and a second cultivar is planted at different distances from the donor as the pollen recipient. Using this approach, Bateman (1947) reported that the number of outcrosses dropped by half at a distance of 3.77 m from the pollen source and by 99% over a distance of 12 to 15 m. Jones and Brooks (1950) determined the effectiveness of border rows to prevent pollen drift in corn in Oklahoma over 3 yr. They found outcrosses in a distance of 503 m from the pollen donor. Salamov (1940, cited in Jones and Brookes 1950) reported 0.21% outcrosses at 800 m from the donor. A recent study conducted by Luna et al. (2001) investigated the longevity of maize pollen and effectiveness of isolation distance for controlling gene flow caused by pollen drift. They found cross pollination occurring at a distance of 200 m, even though the maximum distance viable pollen could have moved was 32 km, taking into account the local climatic conditions at their experimental side in Nayarit, Mexico.

Possible explanations for the varying results are different methods applied to determine pollen drift and contrasting environmental conditions at the respective experimental sides. Jones and Brooks (1950) conducted their experiment in Oklahoma, a windy state, whereas Raynor et al. (1972) conducted their experiments in New York, characterized by less wind and cooler temperatures than in Oklahoma. However, all studies confirm a short dispersal distance for maize pollen caused by its high settling velocity, more than 50% of the pollen is shed onto the source plant, and sensitivity to desiccation during windborne transport.

## CONCLUSIONS

The isolation requirements for hybrid maize seed production were determined by defining seed purity standards based on phenotypic characteristics of a cultivar and a minimum purity of 95%, i.e., the amount of plants resembling the cultivar's described and protected phenotype. However, with the advent of cultivars carrying transgenes and the recent demand for non-GM cultivars, these standards may not be sufficient for non-GM seed production. It must be questioned whether an economical non-GM seed and crop production can be assured, taking a low "background" level of GM pollen into account. Jones and Newell (1948) stated that these relatively low percentages of total pollen caught at 300 m represent considerable numbers of pollen grains and must be considered omnipresent sources of contamination in field production. Given this "pollen background," the Association of Official Seed Certifying Agencies requires a minimum purity of 95%, knowing that higher levels of purity are hard to achieve and that purity levels of 100% can neither be reached nor guarantied. Therefore, it is necessary to discuss meaningful and acceptable threshold levels of GMO contamination in non-GM crop production along the entire crop production value chain. The European Commission initiated projects to develop scenarios for coexistence of genetically modified, conventional, and organic crops in European agriculture to determine 1) the admixture of GMO in conventional non-GM products; 2) the possibility to reach a certain GMO threshold; and 3) the necessary actions to ensure that GMO admixtures are below a defined threshold and their respective costs, assuming that in a geographic region 10 and 50% of a specific crop acreage is devoted to GM cultivars (http://www.jrc.cec.eu.int/download/GMCrops_coexistence.pdf, confirmed 10-18-2002). For maize, model calculations and simulations showed that conventional farmers, producing GM and non-GM maize, will find GMO admixtures of up to 2.2%. This admixture can be reduced to reach a threshold between 0.5 and 0.7% by using larger distances between non-GMO and GMO fields and different maturity groups for transgenic and conventional maize cultivars. A threshold of 0.1 could not be reached in any of the investigated scenarios. The threshold levels will depend on the species' reproduction biology, possibilities to confine pollen to prevent pollen drift or transport by insects, availability of adequate models to predict pollen dispersal, and public acceptance. More information on the parameters determining pollen drift in all crops that are target of genetic modification is needed. This information is critical to develop accurate models to predict pollen dispersion. On the basis of these models, effective confinement or isolation strategies and policies can be developed. In Germany, a project is underway to measure all critical parameters determining maize pollen drift. This immense database will be used to develop mathematical models that allow simulation of the movement of

pollen clouds under specific parameter settings (German Federal Ministry for Education and Research, Project number 0312167).

## REFERENCES

Bateman, A.J. 1947. Contamination of seed crops. Heredity 1: 235–246.

Buitink, J., C. Walters-Vertucci, F.A. Hoekstra, O. Leprince. 1996. Calorimetric properties of dehydrating pollen; Analysis of a desiccation-tolerant and an intolerant species. Plant Physiology 111: 235–242.

Di-Giovanni, F., and P.G. Kevan. 1991. Factors affecting pollen dynamics and its importance to pollen contamination: a review. Canadian Journal of Forest Research 21: 1155–1170.

Di-Giovanni, F., P.G. Kevan, and M.E. Nasr. 1995. The variability in settling velocities of some pollen and spores. Grana 34: 39–44.

Emberlin, J., B. Adams-Groom, and J. Tidmarsh. 1999. The dispersal of maize (*Zea mays*) pollen. A report based on evidence available from publications and internet sites. A report commissioned by the Soil Association: National Pollen Research Unit, University College Worcester, Worcester, UK.

Hauser, T.P., R.B. Jorgensen, and H. Ostergard. 1997. Preferential exclusion of hybrids in mixed pollinations between oilseed rape (*Brassica napus*) and weedy *B. campestris* (Brassicaceae). American Journal of Botany 84: 756–762.

Hauser, T.P., R.B. Jorgensen, and H. Ostergard. 1998. Fitness of backcross and $F_2$ hybrids between weedy *Brassica rapa* and oilseed rape (*B. napus*). Heredity 81: 436–443.

Jemison, J.M. Jr., and M.E. Vayda. 2001 Cross pollination from genetically engineered corn: wind-transport and seed source. AgBioForum 4: 87–92.

Jones, M.D., and J.S. Brooks. 1950. Effectiveness of distance and border rows in preventing outcrossing in corn. Oklahoma Agricultural Experimental Station. Bulletin T-38.

Jones, M.D., and L.C. Newell. 1948. Longevity of Pollen and Stigmas of Grasses: Buffalo-grass. *Buchloe dactyloides* (Nutt.) Engelm., and Corn *Zea mays* L. Journal of the American Society of Agronomy 40: 195–204.

Luna S.V., J. Figueroa M., B. Baltazar M., R. Gomez L., R. Townsend, and J. B. Schoper. 2001. Maize pollen longevity and distance isolation requirements for effective pollen control. Crop Science 41: 1551–1557.

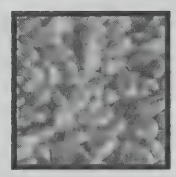
Purseglove, J.W. 1972. Tropical crops. Longman Group, London.

Raynor, G.S., C.O. Eugene, and V.H. Janet. 1972. Dispersion and deposition of corn pollen from experimentqal sources. Agronomy Journal 64: 420–427.

Rodgers, H.J., and H.C. Parkes. 1995. Transgenic plants and the environment. Journal of Experimental Botany 46: 467–488.

Swanson, B.E., A.J. Sofranko, M.M. Samy, E.D. Nafziger, and D.L. Good. 2001. Value Enhanced Corn and Soybean Production in Illinois, Results of the Illinos Farm Survey. Department of Agricultural and Consumer Economics, College of Agricultural, Consumer, and Environmental Sciences, University of Illinois at Urbana-Champaign, AE 4744. see http://web.aces.uiuc.edu/value/ValEnhCo.pdf, confirmed 10-18-2002.

Treu, R., and J. Emberlin. 2000. Pollen dispersal in the crops maize (*Zea mays*), oil seed rape (*Brassica napus ssp. oleifera*), potatoes (*Solanum tuberosum*), sugar beet (*Beta vulgaris* ssp. *vulgaris*) and wheat (*Triticum aestivum*). A report based on evidence from publications. A report commissioned by the Soil Association: National Pollen Research Unit, University College Worcester, Worcester, UK.



# BT CORN, REFUGES, AND MONARCH BUTTERFLIES: CHALLENGES FOR ENTOMOLOGISTS AND GROWERS

**Richard L. Hellmich**

## INTRODUCTION

Transgenic corn with resistance to European corn borer, *Ostrinia nubilalis*, has been commercially available since 1996. Inserting a gene from the soil bacterium *Bacillus thuringiensis* (Bt) has genetically modified the corn plant to produce a protein that is toxic to many types of moth larvae, particularly European corn borer. As a biological insecticide, *B. thuringiensis* has been used for decades for the control of moth, beetle, and fly pests. These insecticides are environmentally friendly because they break down rapidly and have no effect on mammals, birds, aquatic life, or beneficial insects. Transgenic Bt corn is welcomed by many growers because it provides yield protection, reduces ear molds, and, at least in some areas of the United States, reduces the use of chemical insecticides. Entomologists, however, have been challenged by two main Bt corn issues: insect resistance management and nontarget insects. Accordingly, growers have been challenged to be good stewards of the technology by implementing recommended insect resistance management (IRM) practices, plus many have been interested in the nontarget insect debates, especially those related to Bt corn and monarch butterflies. This talk outlines current IRM recommendations for moth-active Bt corn and summarizes recent research on Bt corn and monarch butterflies.

## INSECT RESISTANCE MANAGEMENT

Because Bt corn is so effective, many scientists and growers are concerned that planting too much Bt corn can lead to the development of resistant European corn borers. Many insects have developed resistance to pesticides; for example, corn rootworm beetles in Nebraska have developed resistance to chemical insecticides (Wright et al. 2000). Just as other insects have developed resistance to conventional insecticides, insects could develop resistance to Bt crops. Insects have a greater chance of developing resistance when insecticides are used frequently and at high concentrations. The risk of resistance development is high for Bt corn because Bt toxins are expressed in high amounts throughout the growing season. To prevent the loss of this valuable management tool, IRM guidelines have been established to delay or stop the development of European corn borer resistance.

Growers in Illinois should plant at least 20% of their corn crop as non-Bt corn (called refuge). The intention is that potential rare resistant European corn borer adults emerging from Bt corn will mate with plentiful susceptible adults emerging from refuge corn. These matings lessen selection pressure by diluting resistance genes in the population. For the refuge to be effective, it must be planted close enough to Bt corn to encourage random mating of susceptible and resistant moths. Refuge corn should be located within ½ mile of Bt corn; closer is better. Planting a refuge is not something growers can do at

the last minute. Growers should have a refuge-planting plan established before ordering seed. When possible, growers should try to select Bt and non-Bt hybrids with similar maturities and plant them at the same time. This approach ensures that corn types will have a similar attractiveness to European corn borer.

Field planting options include separate fields, blocks within fields, strips within fields, and perimeter plantings. Growers should choose the method that best fits their farming plan and equipment. Seed mixtures, however, are highly discouraged because research suggests that mixing Bt and non-Bt seed could lead to faster selection for resistant insects (Davis and Onstad 2000). Because susceptible moths are an important part of IRM, insecticide applications in the refuge fields reduce European corn borer populations and the value of refuge corn. Thus, growers should monitor insect infestations in these fields and apply insecticide only when economic thresholds are exceeded. Use of *B. thuringiensis* biological insecticides should be avoided because it, too, can lead to the development of resistance. Seed companies require growers when they purchase Bt corn seed to sign a contract stating that they will plant a refuge. Regardless of whether resistance management is regulated, it just makes good sense. Bt is a valuable tool that can save growers time and money. Good IRM stewardship ensures this technology will be available for future generations of growers.

## Bt CORN AND MONARCH BUTTERFLIES

A correspondence to *Nature* nearly 4 yr ago reported a preliminary laboratory study that suggested pollen from Bt corn could be hazardous to the larvae of the monarch butterfly, *Danaus plexippus*. Losey et al. (1999) showed that young monarch larvae given no choice but to feed on milkweed, *Asclepias curassavica*, leaves dusted with pollen from Bt corn hybrid ate less, grew more slowly, and had a significantly higher mortality rate than larvae feeding on leaves dusted with nontransgenic pollen. Based on this study, the authors questioned the environmental safety of Bt corn and called for scientific investigations.

In response to the Bt corn pollen and monarch questions, several researchers have conducted detailed studies to evaluate the effects of Bt corn pollen on monarch larvae. Results of these studies and a black swallowtail, *Papilio plexippus*, study were published as a group of six papers in the Proceedings of the National Academy of Sciences USA (PNAS, http://www.pnas.org/content/vol98/ issue21/ #AGRICULTURAL_SCIENCES). A formal risk assessment was conducted that addressed toxicity of Bt corn pollen and whether monarch larvae are exposed to harmful levels of Bt corn pollen (Sears et al. 2001). The following is an overview of these investigations and important related events.

## REGISTRATION AND RISK ASSESSMENT

Plants that have been genetically modified for insect protection are registered by the U.S. Environmental Protection Agency (EPA) before being made commercially available. The registration process requires several tests to be conducted on these plants and the transgenic proteins that are expressed by these plants to ensure there are no effects on mammals, birds, nontarget invertebrates (excluding insect relatives of targeted insects), and aquatic species. Nontarget insects that are tested include ladybird beetles, green lacewings, parasitic wasps, collembola, and honey bees. The first batteries of tests are called tier 1 tests. During tier 1 testing organisms are fed 10 to 100 times the amount of the protein that they would likely encounter in nature. None of the Bt Cry proteins specific to moths that were expressed in corn showed effects on tested organisms. The nontarget insect results support previous research with natural *B. thuringiensis* that suggest the Bt proteins are highly specific.

But it is not surprising that relatives of the European corn borer, that is, other moths and butterflies, might be affected by Bt Cry proteins. EPA did take that point into account when the Agency reviewed the Bt corn data. Note that effect on related but nontarget species has not been a registration issue with chemical insecticides because these insecticides are broad spectrum and generally impact all insects that are exposed to the chemicals. The toxicity of Bt Cry proteins to larval stages of butterflies and moths is well known (Kreig and Langenbruch 1981, Peacock et al. 1998). Many studies, particularly those conducted on the extensive use of Bt sprays in forests for gypsy moth control, have shown that Bt Cry proteins can adversely affect nontarget moths and butterflies (Miller 1990, Johnson et al. 1995). But field data from

these studies indicated only a temporary reduction in moth and butterfly populations during prolonged Bt use, widespread irreversible harm was not apparent (Hall et al. 1999). Based on such information, EPA made the assumption that *B. thuringiensis* is a hazard to all moths and butterflies but that exposure from agricultural uses of Bt was not expected to be as high as in forest spraying. Bt corn was not expected to significantly impact nontarget butterflies and moths because of low exposure (USEPA 1995). The question is not whether Bt corn has no impact on nontarget insects (no tolerance is an unreasonable expectation), but rather does Bt corn have an unreasonable impact on nontarget insects such as the monarch butterfly.

## RESEARCH OVERVIEW

In February 2000, the United States Department of Agriculture–Agricultural Research Service (USDA–ARS) hosted a monarch research workshop in Kansas City, MO. More than 30 government, academic, and industry scientists participated in the workshop. A steering committee, including Adrianna Hewings (USDA–ARS), Eldon Ortman (Purdue University), Mark Scriber (Michigan State University), Eric Sachs (Monsanto), and Margaret Mellon (Union of Concerned Scientists), was formed to provide guidance for the workshop and subsequent activities. The goal of the workshop was to identify research priorities regarding Bt corn and monarch butterflies and establish cooperation among researchers. Several scientists that attended the workshop have continued to work together to identify gaps and overlaps in research, promote an open exchange of information, and provide a coherent research agenda.

Risk assessment involves developing data about hazard identification, dose-response relationships, and exposure assessment. Consortium research has focused on dose-response relationships and exposure assessment. To formulate a quantitative risk assessment, the level of toxicity must first be determined. Generally dose-response studies are conducted to determine estimates of the $LC_{50}$, or lethal concentration that kills 50% of tested insects. Dose-response relationships of Bt Cry proteins were conducted by Blair Siegfried (University of Nebraska) with monarch neonates (newly hatched larvae). Neonates were exposed for 7 d to purified Bt toxins incorporated into an artificial diet. Four Bt toxins (Cry1Ab, Cry1Ac, Cry9C, and Cry1F) were tested. Results of these studies indicate that monarch larvae are highly sensitive to certain Bt toxins, whereas others do not affect them (Hellmich et al. 2001). Monarch neonates were most sensitive to Cry1Ab and Cry1Ac. In contrast, Cry9C and Cry1F were considerably less toxic; therefore, risks associated with corn plants expressing one or the other of these proteins are likely to be reduced compared with the risks posed by corn expressing Cry1Ab and Cry1Ac proteins. The Cry1Ac event, DBT418, and the Cry1Ab event 176 are in the process of being phased out, and have received little further attention. Consequently, most of the exposure questions have focused on the Cry1Ab events BT11 and MON810.

Several studies were conducted to address the exposure question, including looking at monarch larvae overlap with corn pollen shed, milkweed distribution, monarch use of milkweed in agricultural and nonagricultural conditions, and patterns of pollen deposition. Phenology studies indicate that there is a greater temporal overlap between monarch larvae and corn anthesis in the northern than the southern part of the summer breeding range, because of earlier pollen shed in the south (Oberhauser et al. 2001). Due to the prevalence of agricultural land, most of the monarchs produced in the upper Midwest are likely to originate in cornfields or other agricultural habitat.

Pollen density was highest (avg. 171 grains/$cm^2$) inside the cornfield and was progressively lower from the edge of the field outward, falling to 14 grains/$cm^2$ at 2 m (Pleasants et al. 2001). Monarch larvae will not encounter high pollen densities outside of cornfields and rarely will encounter densities of more than 1000 pollen grains/$cm^2$ inside the field (Pleasants et al. 2001). Laboratory bioassay data suggest that the no observable effect level of pollen for Cry1Ab events BT11 and MON810 is greater than 1,000 pollen grains/$cm^2$. Laboratory bioassay data suggest that for BT11 and MON810 there was no observable effect on monarch larvae when the pollen density was below 1,000 pollen grains/$cm^2$ (Hellmich et al. 2001). Pollen from one rarely planted Bt hybrid that has not been reregistered (event 176) was harmful to larvae at levels of pollen commonly encountered in cornfields. Field studies corroborate the BT11 and MON810 findings, because no acute effects were observed when monarch larvae fed on milkweed leaves dusted with natural levels of pollen from BT11 and MON810 corn hybrids (Stanley-Horn et al. 2001).

Proven methods of risk assessment were used by a consortium of scientists to investigate the potential

impact Bt corn pollen on the monarch butterfly. Toxicity of Bt corn pollen and larval exposure to harmful levels of pollen were investigated. Research indicates that the potential risk to monarch butterfly populations from Bt corn pollen is negligible. Toxicity of Bt corn pollen (except pollen from event 176 corn) is low and exposure of monarch larvae to Bt corn pollen also is low. Laboratory and field studies show no acute toxic effects at any pollen density that would be encountered in the field. Other factors mitigating exposure of larvae include the variable and limited overlap between pollen shed and larval activity periods. The approach taken by the consortium has been cited as a model for evaluating potential environmental impacts of transgenic plants (Irwin and Krishna 2002).

## REFERENCES


Davis, P. M., and D. W. Onstad. 2000. Seed mixtures as a resistance management strategy for European corn borers (Lepidoptera : Crambidae) infesting transgenic corn expressing Cry1Ab protein. Journal Economic Entomology 93: 937–948.

Hall, S. P., J. B. Sullivan, and D. F. Schweitzer. 1999. Assessment of risk to non-target macro-moths after BTK application to Asian Gypsy Moth in the Cape Fear region of North Carolina. USDA Bulletin No. FHTET-98-16.

Hellmich, R. L., B. D. Siegfried, M. K. Sears, D. E. Stanley-Horn, H. R. Mattila, T. Spencer, K. G. Bidne, M. J. Daniels, and L. C. Lewis. 2001. Monarch larvae sensitivity to *Bacillus thuringiensis*-purified proteins and pollen. Proceedings of the National Academy Sciences USA 98: 11925–11930.

Irwin, R., and P. J. Krishna. 2002. Non-target impacts of Bt corn: a risk assessment, pp. 6–8. Information Systems for Biotechnology (ISB) News Report, April.

Krieg, A. and G.A. Langenbruch. 1981. Susceptibility of arthropod species to *Bacillus thuringiensis*, pp. 837-896. In: Microbial control of pests and plant diseases, 1970-1980, ed. H.D. Burges, Academic Press, New York.

Johnson, K. S., J. M. Scriber, J. K. Nitao, and D. R. Smitley. 1995. Toxicity of *Bacillus thuringiensis* var. kurstaki to three nontarget Lepidoptera in field studies. Environmental Entomology 24: 288–297.

Losey, J. E., L. S. Rayor, and M. E. Carter. 1999. Transgenic pollen harms monarch larvae. Nature 399: 214.

Miller, J.C. 1990. Field assessment of the effects of a microbial pest control agent on nontarget Lepidoptera. American Entomologist 36: 135–139.

Oberhauser, K. S., M. Prysby, H. R. Mattila, D. E. Stanley-Horn, M. K. Sears, G. Dively, E. Olson, J. M. Pleasants, W.-K. F. Lam, and R. L. Hellmich. 2001. Temporal and spatial overlap between monarch larvae and corn pollen. Proceedings of the National Academy Sciences USA 98: 11913–11918.

Peacock, J. W., D. F. Schweitzer, F. Dale, J. L. Carter, and N. R. Dubois. 1998. Laboratory assessment of the effects of *Bacillus thuringiensis* on native Lepidoptera. Environmental Entomology 27: 450–457.

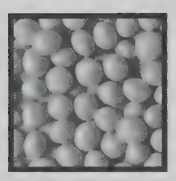
Pleasants, J. M., R. L. Hellmich, G. P. Dively, M. K. Sears, D. E. Stanley-Horn, H. R. Mattila, J. E. Foster, P. L. Clark, and G. D. Jones. 2001. Corn pollen deposition on milkweeds in and near cornfields. Proceedings of the National Academy Sciences USA 98: 11919–11924.

Sears, M. K., R. L. Hellmich, B. D. Siegfried, J. M. Pleasants, D. E. Stanley-Horn, K. S. Oberhauser, and G. P. Dively. 2001. Impact of *Bt* corn pollen on monarch butterfly populations: A risk assessment. Proceedings of the National Academy Sciences USA 98: 11937–11942.

Stanley-Horn, G. P. Dively, R. L. Hellmich, H. R. Mattila, M. K. Sears, R. Rose, L.C. H. Jesse, J. E. Losey, J. J. Obrycki, and L. C. Lewis. 2001. Assessing the impact of Cry1Ab-expressing corn pollen on monarch butterfly larvae in field studies. Proceedings of the National Academy Sciences USA 98: 11931–11936.

USEPA, 1995. Pesticide fact sheet for *Bacillus thuringiensis* susp. *kurstaki* CryI(A)b delta-endotoxin and the genetic material necessary for the production (plasmid vector pCIB4431) in corn. EPA publication number EPA731-F-95-004.

Wright, R. J., M. E. Scharf, L. J. Meinke, X. Zhou, B. D. Siegfried, and L. D. Chandler. 2000. Larval susceptibility of an insecticide-resistant western corn rootworm (Coleoptera: Chrysomelidae) population to soil insecticides: laboratory bioassays, assays of detoxification enzymes, and field performance. Journal Economic Entomology 93: 7–13.



# INTEGRATING INTEGRATED WEED MANAGEMENT INTO GLYPHOSATE-RESISTANT CROPPING SYSTEMS

**Aaron Hager**

The introduction and commercialization of glyphosate-resistant soybean varieties and corn hybrids has, in many ways, dramatically altered weed management approaches. Estimates place the adoption of genetically modified organism (GMO) soybean (principally glyphosate-resistant varieties) at approximately 75% of the U.S. soybean acreage[1]. The adoption of this technology has, in many respects, simplified weed control for many producers. For example, soybean producers can use a single active ingredient (glyphosate) for postemergence control of many broadleaf and grass weed species. Application rates can be adjusted according to weed spectrum and size. No concerns exist for rotational crop injury from herbicide carryover. Simply stated, this new weed control "system" has worked well for many producers.

But does this system perhaps work too well? Does this system simplify weed management decisions to the extent that integrated weed management consists only of one or more applications of glyphosate? Some might argue that "if the system ain't broke, don't fix it!" But if "problems" of one sort or another do develop that reduce the effectiveness of this system, what will soybean producers do? Will there be new soybean herbicide active ingredients in the near future that could remedy any of these potential problems? Will the weed spectrum change somehow in response to the widespread use of glyphosate? Perhaps we should consider another suggestion, that "an ounce of prevention is worth a pound of cure."

## NEW SOYBEAN HERBICIDES ON THE HORIZON

Some may find a degree of comfort in that there will always be new soybean herbicide active ingredients that come along just in time to save the day/farm if and when problems develop in the "old" system. For example, on several occasions, weed scientists have heard the statement "I plan to continue to use glyphosate until it's no longer effective. By that time, someone else will have brought out a new herbicide to solve the problem." True, in years past this happened; introduction of new soybean herbicide active ingredients was an almost annual event. Now, however, it may not be as prudent to simply use the system until it breaks, all the while anticipating a new "cure" will be along shortly.

University researchers have usually evaluated a new herbicide active ingredient for between 1 and 4 yr before the product is commercialized. Although formulations of existing soybean herbicide active ingredients continue to change, novel active ingredients are not finding their way from the laboratory to the field as rapidly as in years past. It is unlikely that many (or perhaps any) new herbicide active ingredients will be introduced into the soybean market anytime during the foreseeable future, perhaps none during the next 3 to 4 yr. So, if the effectiveness of current soybean active ingredients declines, there may NOT be that new soybean herbicide that comes along and saves the day/farm. Consider waterhemp. Waterhemp is tough enough to control with the few effective postemergence soybean herbicides on the

[1] United States Department of Agriculture National Agricultural Statistics Service June 2002 report.

market today. What would happen if the utility of one or more of these options was lost? Read on!

## CHANGES IN THE WEED SPECTRUM

What is meant by "changes in the weed spectrum"? There are several ways in which the weed spectrum in any given field can change over time. Weed species that were not seen previously in a field can become more prevalent and problematic; repeated applications of specific herbicides may select for weed biotypes resistant to that herbicide; or the biology or growth characteristics of one or more weed species may change in response to changes in agronomic practices. Some recent examples of changes in the weed spectrum by each of these mechanisms may help illustrate the point that weeds today do not necessarily grow like they did years ago.

### "New" weed species becoming more prevalent

Reduced tillage production practices occur on more acres today than 25 yr ago. When tillage is reduced, it is not uncommon to begin encountering more biennial and perennial weed species such as poison hemlock, hemp dogbane, and common pokeweed. Without sufficient tillage to adequately disturb the root system of perennial weed species, these weeds can often flourish in reduced tillage fields. If tillage is eliminated after crop harvest, winter annual weed species frequently become well established and are able to survive over the winter to cause problems the following spring. Some may argue, however, that the prevalence of winter annual weed species today may be not only related to reduced tillage but also to the reduced use of soil residual herbicides. Think back to the 1980s and early to mid-1990s, a time when few producers were considering applying soil residual herbicides in the fall to control winter annual weed species. Reduced tillage practices were common then, but so was the use of soil residual herbicides. Today, reduced tillage is still a common production practice, but soil residual herbicides are not used to near the extent they once were. Many would agree that biennial, perennial, and winter annual weeds are more common today than 25 yr ago and that these weeds didn't necessarily "change" over time, but rather adapted to changes (reduced tillage, less use of soil residual herbicides) imposed on the production system.

### Weed biotypes resistant to herbicides

In 1993, the list of herbicide-resistant weed biotypes in Illinois was but a small fraction of today's list. Many Illinois producers have had the unpleasant experience of contending with one or more herbicide-resistant biotypes, and (unfortunately) the weeds continue to thwart many of our management tools. It's become somewhat "old news" that much of the Illinois waterhemp population is resistant to acetolactate synthase-(ALS) inhibiting herbicides or that many populations are resistant to triazine herbicides. Foes et al. (1998) conducted research on an Illinois waterhemp biotype with resistance to ALS-inhibiting and triazine herbicides, one of the first reported instances of a summer annual weed species with resistance to more than one herbicide family. Unfortunately, the story doesn't end there. Recent research has identified an Illinois waterhemp biotype with resistance to ALS-inhibitors, triazines, and also protoporphyrinogen oxidase-(PPO) inhibiting herbicides (yes, three-way resistance has become a reality). Leave it to waterhemp to run up the score!

So, what options remain for postemergence control in soybean of a waterhemp biotype with resistance to three herbicide families? The answer is about as surprising as someone telling you the sun rises in the east and sets in the west. Four soybean herbicides can provide postemergence control of waterhemp; three are no longer effective because the biotype is resistant to PPO inhibitors, so that leaves only glyphosate. It doesn't require much imagination to conclude that if there is only one viable option remaining, that will be the option the producer has to use. Will the selection pressure of using only glyphosate result in a glyphosate-resistant waterhemp biotype? Some have suggested that selecting for weed biotypes with resistance to glyphosate is unlikely to happen (Bradshaw et al. 1997), but glyphosate-resistant horseweed (marestail) biotypes from Delaware and Tennessee have been reported recently (VanGessel 2001). True, horseweed isn't waterhemp and to date no waterhemp biotypes with actual resistance to glyphosate have been documented. However, several researchers have reported waterhemp populations with "decreased sensitivity" to glyphosate (Zelaya and Owen 2000, Patzoldt et al. 2002). Should these examples (documented glyphosate-resistant horseweed, waterhemp biotypes with reduced sensitivity to glyphosate) be ignored, or perhaps should they been seen as evidence that weed species can and have adapted to extensive glyphosate use?

### Changes in weed biology

A contemporary example of a change in weed biology is that of giant ragweed. Surveys of Illinois producers conducted during the 1980s indicated giant ragweed was not ranked among the top 10 most prevalent weed species. Today, however, only waterhemp ranks above giant ragweed on the most recent producer survey. Weed scientists at the University of Illinois recently have determined the competitive ability of these two weed species with soybeans. Waterhemp, at a density of approximately 89 plants $m^{-2}$, can reduce soybean yield up to 31% (Hager et al. 2002), whereas giant ragweed at 15 plants $m^{-2}$ can reduce soybean yield up to 87% (Wax et al. 2002). These data indicate giant ragweed should be taken very seriously!

Research conducted by Stoller and Wax (1973) in the late 1960s and early 1970s demonstrated giant emergence was essentially complete by the beginning of May. During this time, producers were generally able to control most giant ragweed populations with preplant tillage. However, recent research by weed scientists at the University of Illinois has shown that giant ragweed emergence in agronomic production fields can continue well into June and sometimes even into July. These results show giant ragweed has adapted its biology to changes in how producers grow their crops.

## LOOKING TO THE FUTURE

The examples described previously illustrate how weed species have and continue to adapt to changes in production practices. In some instances, weeds adapt in response to a single selection factor, whereas other times the adaptation is due to multiple changes in production practices. Whether single or multiple factors are involved, it is important to remember that weeds will continue to adapt and challenge us. These examples should further illustrate the need for an integrated approach to weed management. Integrated weed management introduces multiple tactics to control weeds and slow the rate at which weeds are able to adapt to a single management approach.

Glyphosate-resistant soybean varieties offer may advantages to soybean producers, but as the previous examples illustrate, over-reliance on a single management option can lead to new weed management challenges. The weed spectrum in many Illinois soybean fields today is such that a singular management strategy (e.g., a single postemergence herbicide application) may not always provide consistent control. Introducing an integrated weed management approach into glyphosate-resistant cropping systems may well stave off some of these potential new challenges, enhancing the long-term effectiveness of this valuable weed control strategy. Is an ounce of prevention worth a pound of cure?

## REFERENCES


Bradshaw, L. D., S. R. Padgette, S. L. Kimball, and B. H. Wells. 1997. Perspectives on glyphosate resistance. Weed Technology 11: 189–198.

Foes, M. J., L. Liu, P. J. Tranel, L. M. Wax, and E. W. Stoller. 1998. A biotype of common waterhemp (*Amaranthus rudis*) resistant to triazine and ALS herbicides. Weed Science 46: 514–520.

Hager, A. G., L. M. Wax, E. W. Stoller, and G. A. Bollero. 2002. Common waterhemp (*Amaranthus rudis*) interference in soybean. Weed Science 50: 607–610.

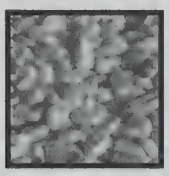
Patzoldt, W. L., A. G. Hager, and P. J. Tranel. 2002. Variable herbicide responses among Illinois waterhemp (*Amaranthus rudis* and *A. tuberculatus*) populations. Crop Protection 21: 707–712.

Stoller, E. W. and L. M. Wax. 1973. Periodicity of germination and emergence of some annual weeds. Weed Science 49: 224–229.

VanGessel, M. J. 2001. Glyphosate-resistant horseweed from Delaware. Weed Science 49: 703–705.

Wax, L., K. Maertens, and C. Sprague. 2002. Giant ragweed: old weed, new problem. Proceedings, Agronomy Day 2002.

Zelaya, I. A., and M.D.K. Owen. 2000. Differential response of common waterhemp (*Amaranthus rudis* Sauer) to glyphosate in Iowa. Proceedings of the North Central Weed Science Society 55: 68.



# CORN ROOTWORM MANAGEMENT WITH GENETICALLY ENGINEERED CORN HYBRIDS

**Jon Tollefson**

The previous speakers in this symposium may have raised some questions concerning the prudence of deploying genetically engineered crops. However, growers, especially those that must handle toxic synthetic pesticides, may realize greater safety through the use of plant-produced pesticides (biopesticides), especially those who plant corn following corn (continuous corn). Approximately 70–80% of the Corn Belt acres that are planted to continuous corn are treated with an insecticide at planting. Although the amount of insecticide used should be declining because the number of acres planted to continuous corn has declined, changes in insect biology have worked against the reduced need for insecticide. Since 1995, the soybean area infested by the western corn rootworm, resulting in an economic infestation in the corn planted the following year, has expanded and the injury caused continues to be severe. Northwest of Illinois, where this strain of western corn rootworm is not found, the northern corn rootworm has overcome crop rotation through a different biological change. A strain of the northern corn rootworm can remain in diapause in the soil for two winters ("extended diapuse"), with grubs hatching every other year and attacking corn grown in an annual rotation with soybean. During the past two seasons, this extended diapause strain of the northern corn rootworm has been particularly abundant, causing an increase in the number of acres of rotated corn treated in northwestern Iowa, southern Minnesota, and southeastern South Dakota.

Monsanto has submitted a registration for event MON863, a genetically engineered corn that produces the Cry3Bb Bt toxin. Corn hybrids that contain this gene suffer little injury when planted into corn rootworm-infested soil. As with all plant-produced pesticides, the Environmental Protection Agency has required an insect resistance management (IRM) plan as part of the registration. Even without this requirement, it would seem to be in the best interest of growers to support good stewardship of this technology because they should benefit directly through the handling of less insecticide.

## CAN ROOTWORMS ADAPT TO CONTROL TACTICS?

This audience is probably most aware of the ability of corn rootworms to adapt to control tactics if they are practiced routinely. You are very close to where it was first reported that western corn rootworm females were laying eggs in soybean and are probably in an infested area now (Levine et al. 2002). Although this example may be one of the more recent and severe examples of corn rootworm adaptability, it is not isolated. The northern corn rootworm also has adapted to crop rotation. Between 1965 and 1986, the proportion of the northern corn rootworm population that remained in the egg stage for two winters increased from 0.3 to nearly 40% (Chiang 1965, Krysan et al. 1986). Both of these examples demonstrate that corn rootworms can adapt to cultural control practices if they are applied routinely throughout a corn production area.

More troubling is that rootworms also have adapted to insecticides. In 1947 (Hill et al. 1948) demonstrated that insecticides offered protection from corn rootworm larval feeding. By 1962, the western corn

rootworm had developed resistance to those same insecticides (Ball and Weekman 1962). The increase in tolerance occurred because of the routine application of broadcast treatments over large geographic areas. More recently, insecticide resistance is developing to the routine broadcast application of an organophosphorous insecticide (Meinke et al. 1998).

A common theme in all of these examples is the routine use of treatments that affect all individuals within the field, i.e., broadcast use of insecticides instead of bands and rotation of whole fields to nonhost crops. Isn't this how genetically engineered corn hybrids are likely to be deployed; whole fields planted to single varieties? If many fields in a region are planted to hybrids that express the same plant-produced biopesticide, there is also potential for areawide resistance selection, as occurred with crop rotation and insecticides. Consequently, not only will it be a legal requirement that stewardship be practiced with the transgenic, corn rootworm-resistant hybrids but also it seems in the best interest of the growers choosing to use the technology.

## POSSIBILITIES FOR STEWARDSHIP FOR CORN ROOTWORM TRANSGENIC TECHNOLOGY

Ways that the development of resistance to a biopesticide can be slowed or eliminated include 1) reducing the selection pressure, 2) diluting the resistant genes through mating with susceptible individuals, or 3) eliminating the genes (i.e., killing individuals that carry the genes). The second option was taken with the European corn borer because the resistant corn hybrids produced a high dose of toxin, thus there were fewer individuals that survived to mate. Also, the adult moths were thought to be mobile, encouraging mating with individuals from different cornfields. As a result, European corn borer stewardship is based on diluting any resistant genes that may exist by planting susceptible, nontransgenic corn within a half mile of a field planted to a corn borer-resistant transgenic corn.

The corn rootworm situation is different because of the transgenic event being registered, the biology of the insect, and the management options available. The European corn borer events that have been registered can be appropriately classified as "high-dose" events, that is, they produce levels of toxin that are at least 25 times higher than that required to kill European corn borer larvae. This definition is not true for the corn rootworm transgenics currently under registration; corn rootworm larvae can survive on this event.

The biology of the corn rootworm differs from the European corn borer in several ways: the corn borer has two generations per year, the rootworms have one; the corn borer has a wide host range, the corn rootworm survives only on corn and a few related grasses; both sexes of the corn borer are thought to be mobile and fly between fields, rootworms may disperse less; European corn borer larvae move from plant to plant within a corn row, corn rootworm larvae are in the soil and interplant dispersal is more difficult; and the mating behavior of the two species is different.

These differences in insect biology relate directly to differences in management options that are available for the pests. Unlike the European corn borer, the corn rootworm cannot invade a field after the corn has been planted. For corn rootworm, therefore, it is possible to estimate the likelihood of a larval infestation before a decision is made as to which crop to plant or whether a transgenic or nontransgenic hybrid is selected. The use of insecticides to prevent corn rootworm larval injury is still an economic and viable option with the corn rootworm, whereas controlling both generations of the European corn borer with insecticides is more difficult and can be more costly.

These differences between the corn rootworm and European corn borer susceptibility to biopesticides, their biology, and management suggest that it would be unlikely that an IRM plan for the corn rootworm should be the same as that for the European corn borer and prompted the North Central Region Corn Rootworm Technical Committee (NCR-46) to state in their letter to the Environmental Protection Agency (dated 29 May 2001),

"The resistance management plan proposed by Monsanto is essentially the same plan that evolved for European corn borer (ECB) and transgenic corn expressing the Cry1Ab toxin. The plan is simple, flexible, and easily implemented. While adopting this approach assures subsequent compatibility with IRM plans for ECB, the appropriateness of this "hand-me-down" plan for a completely different group of insects is open to debate. IRM plans for high dose events may not be appropriate for lower-dose events. NCR-46 believes that any IRM plan must first address the unique challenges posed by Cry3Bb, corn

rootworm biology and ecology, and corn rootworm management before optimizing a combined IRM plan for ECB and corn rootworms or addressing practical/logistical issues that affect implementation by farmers."

With these differences between the two pest species in mind, let's consider again the three possibilities for stewardship for the corn rootworm transgenic technology: reducing the selection pressure, diluting the resistant genes, or eliminating the genes completely. The option that was chosen for the European corn borer was diluting resistant genes by planting nontransgenic corn to offer a refuge for Bt-susceptible European corn borers. This option is a possibility for the corn rootworm as well, although the size of the refuge in relation to the transgenic planting is debatable, considering there will be more corn rootworms surviving the lower dose produced in the rootworm transgenic than European corn borers that survive the high dose produced in European corn borer-resistant transgenics. Also, there are susceptible European corn borers produced on hosts other than corn, which wouldn't be true of corn rootworms because of their narrower host range. The refuge-planting options may even be more flexible for the corn rootworm. Because larval movement in the soil is more restricted, planting the refuge within the same field as a seed mix or alternating strips are possibilities.

Planting a refuge does, in effect, reduce selection pressure (option 1), but it does not do so in an intentional way that reduces the yield losses in the nontransgenic planting. Because the corn rootworm females lay eggs in a field during the previous growing season, the likelihood of an infestation can be estimated before planting. Thus, a grower could make a more informed decision as to whether the corn rootworm is not likely to be a problem and no control is needed, a moderate infestation is expected that can be suppressed with a soil insecticide at planting, or whether the infestation is likely to be serious and a transgenic is warranted. This later approach would be a "prescription approach" to stewarding the corn rootworm transgenic technology. The transgenic would only be used when necessary, hopefully reducing the number of acres that are planted to the transgenic, resulting in reduced selection pressure for resistance. Because European corn borer infestations cannot be predicted at planting, this option was not possible with the European corn borer.

The third option, eliminating resistant individuals, was not possible with the European corn borer. Is this also true of the corn rootworm? Not necessarily. Because of the restricted host range of the corn rootworm, where crop rotation is still effective, planting a nonhost crop eliminates corn rootworms that have survived the transgenic and laid eggs in the field. It is also likely that there will be additional transgenic corn rootworm varieties registered and that their modes of action will differ from the one currently being registered. Rotating among the different modes of action during subsequent growing seasons will reduce the selection for resistance to any of the modes of action and prolong their effectiveness.

## WHAT WILL STEWARDSHIP OF CORN ROOTWORM MANAGEMENT TRANSGENIC TECHNOLOGIES BE?

Although there are, theoretically, several possible ways of stewarding the new corn rootworm transgenic technologies (see above), currently only one has been suggested by the registrant and is likely to be approved. The IRM plan that will likely be approved for the initial corn rootworm event is planting a refuge to dilute resistant genes should they be present. In Monsanto's revised IRM plan, the refuge is to be planted within or adjacent to a field of their genetically engineered corn. Because rootworm scientists think that a smaller proportion of the corn rootworms disperse among fields than European corn borers and mating is likely to occur closer to where the beetles emerge, rootworm researchers agree that the refuge should be planted closer to the transgenic planting. It is also likely that the registration will be an interim registration during which time critical questions can be researched to craft a more permanent stewardship plan. In their letter to the EPA the NCR-46 committee outlined questions that they agreed should be answered before a permanent stewardship plan is crafted. They include the following:

- "Characterize tissue expression, dose, and the mechanism by which corn rootworms survive on transgenic corn expressing Cry3Bb.
- Continue to quantify movement patterns of corn rootworm larvae when feeding on transgenic (expressing Cry3Bb) and nontransgenic corn.

- Quantify pre- and postmating dispersal of corn rootworm, movement within and between fields, and its implications for IRM.
- Quantify the relative fitness of rootworm individuals that survive on transgenic corn vs. nontransgenic corn.
- Reevaluate the host status of major grassy cornfield weeds and other grasses commonly found near corn; estimate the potential impact these alternate hosts may have on corn rootworm population dynamics.
- Continue to develop toxicological bioassays and resistance monitoring techniques.
- Determine the genetic nature of resistance to corn rootworm-active Cry compounds.
- Improve rearing techniques for certain corn rootworm species to facilitate laboratory and greenhouse bioassays, genetic studies, etc.
- Generate more complete data sets on transgenic efficacy, adult emergence from transgenic corn, etc., for all targeted corn rootworm species.
- Evaluate IRM options other than a refuge strategy, especially if an event is not classified as high dose.
- Examine the impacts of refuge configuration, including seed mixtures, on development of resistance and likelihood of farmer adoption.
- Continue to develop and refine computer simulation models that build on current knowledge to guide development of IRM strategies.
- Reconcile corn rootworm and ECB IRM needs into an optimal IRM plan."

Currently, it seems likely that the Monsanto corn rootworm-resistant corn will receive a temporary registration by this coming growing season. If so, there will be a limited amount of seed for the 2003 crop year. During the next several years, researchers will study the corn rootworm in large blocks of transgenic corn to answer the questions required to design permanent resistance management plans. Growers also should begin to think about what type of product stewardship plans fit their farming practices, to implement those strategies, and to work with researchers to ensure the plan they develop fits accepted, regional farming practices.

## REFERENCES


Ball, Harold J., and Gerald T. Weekman. 1962. Insecticide resistance in the adult western corn rootworm in Nebraska. Journal of Economic Entomology 55: 439–441.

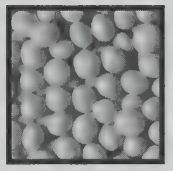
Chiang, H.C. 1965. Survival of northern corn rootworm eggs through one and two winters. Journal of Economic Entomology 58: 470–472.

Hill, R.E., E. Hixson, and M.H. Muma. 1948. Corn rootworm control tests with benzene hexachloride, DDT, nitrogen fertilizers and crop rotations. Journal of Economic Entomology 41: 392–401.

Krysan, J.L., D.E. Foster, T.F. Branson, K.R. Ostlie, and W.S. Cranshaw. 1986. Two years before the hatch: rootworms adapt to crop rotation. Bulletin of the Entomological Society of America. Winter: 250–253.

Levine, E., J.L. Spencer, S.A. Isard, D.W. Onstad, and M.E. Gray. 2002. Adaptation of the western corn rootworm to crop rotation: evolution of a new strain in response to a management practice. American Entomologist 48: 94–107.

Meinke, L.J., B.D. Siegfried, R.J. Wright, and L.D. Chandler. 1998. Adult susceptibility of Nebraska western corn rootworm (Coleoptera: Chrysomelidae) populations to selected insecticides. Journal of Economic Entomology 91: 594–600.



# PRODUCT UPDATE IN WEED MANAGEMENT

**Christy L. Sprague**

This proceedings paper is an overview of label changes and recently registered weed control products for use in field crops. Efficacy data are not presented in this paper; however a handout of weed control results from some of these products will be distributed at the conference.

Label changes and recently registered products will be presented alphabetically by the company that manufactures or distributes the herbicide. Information in this paper includes the properties and intended uses of these weed control products. Further information on the efficacy of these products against certain weed species can be found in the *2003 Illinois Agricultural Pest Management Handbook,* the *Illinois Agronomy Handbook 2003-2004,* and the *2002 University of Illinois Annual Weed Control Research Report.*

### BASF Corporation

**DISTINCT 70WDG** (active ingredients diflufenzopyr and dicamba). There has been a label change in the rotation restriction for Distinct. There is a 30-day rotation restriction before planting any crop, with the exception of corn. Corn can be replanted 7 days or more after application.

**EXTREME 2.17L** (active ingredients imazethapyr and glyphosate). BASF has received a supplemental label for Extreme applications in the fall to control existing vegetation and to provide residual control of winter annual and early spring emerging weeds. Soybeans must be planted in the spring following fall Extreme applications. Fall applications of Extreme should be made after harvest and prior to ground freeze-up at 3 pints per acres with a non-ionic surfactant and nitrogen source.

**G-MAX LITE 5L** (active ingredients dimethenamid-P and atrazine). G-Max Lite is a recently registered premixture containing 2.25 lb ai/gal of dimethenamid-P (Outlook) and 2.75 lb ai/gal of atrazine. G-Max Lite is a selective preemergence herbicide that controls annual grasses, some annual broadleaf weeds, and sedges in field corn, seed corn, sweet corn, popcorn, and grain sorghum. G-Max Lite is similar to Guardsman Max, with the exception of containing less atrazine. G-Max Lite may be applied up to 45 days prior to planting (EPP), preplant incorporated (PPI), preemergence (PRE), and early postemergence (EPOS) to corn up to12 inches tall. Split-applications are recommended if G-Max Lite is applied more than 30 days EPP. Applications rates range from 2.5 to 3.5 pints per acre depending on soil texture and soil organic matter content. A typical use rate of 3.0 pints per acre of G-Max Lite is equivalent to applying 18 fluid ounces of Outlook and 1.0 lb ai of atrazine per acre.

**PROWL 3.3EC** (active ingredient pendimethalin). The fall-applied label for Prowl prior to soybean planting has been extended to cover the entire state of Illinois. Prowl may be surface applied or incorporated in the fall from October 1 to December 31, or until ground freeze. Fall applications of Prowl will not provide season long weed control.

**RAPTOR 1S** (active ingredient imazamox). Raptor, an ALS-inhibiting herbicide, has recently received registration for use in alfalfa. Raptor should be applied early postemergence before annual broadleaf and grass weeds exceed 3 inches in height. Use rates range between 4 and 6 fluid ounces per acre for seedling or established alfalfa grown for forage, hay or seed. There should be at least 20 days between

Raptor application and cutting or feeding alfalfa for forage or hay, and an interval of 70 days between application and harvest of alfalfa seed used for food or feed. Postemergence applications require the addition of an adjuvant (non-ionic surfactant, crop-oil concentrate, or methylated seed oil) and a nitrogen source.

**SCEPTER 70DG** (active ingredient imazaquin). A supplemental label has been granted to BASF for fall applications of Scepter prior to soybean planting. Fall applications of Scepter should be made after harvest and prior to ground freeze-up to provide residual control of winter annual and early emerging summer annual weeds. The use rate is 2.8 ounces per acre and ***do not*** make more than one application per year.

### Bayer CropScience

**OPTION 35WDG** (active ingredient foramsulfuron). Option is the only herbicide registered in 2002 that contains a new active ingredient. Option is a sulfonylurea herbicide and is labeled for postemergence use in field corn. Use rates range from 1.5 to 1.75 ounces per acre. Broadcast applications may be made when corn is between 0 to 16 inches in height or through the V5 growth stage, whichever is more restrictive. Drop nozzles must be used when corn is between 16 and 36 inches in height. Applications of Option must include a methylated seed oil and a nitrogen fertilizer (UAN or AMS). The use of non-ionic surfactants or crop oil concentrates will result in unacceptable weed control. Do not make more than two applications or apply more than 3.5 ounces of Option per acre per year.

Option has good activity on several grass and broadleaf weed species. Grasses that Option controls include: foxtails, fall panicum, barnyardgrass, shattercane, johnsongrass, quackgrass, and wirestem muhly. Some of the broadleaf weeds that Option controls are common lambsquarters, pigweeds, velvetleaf, common ragweed, and eastern black nightshade. Since Option is an ALS inhibitor, it will not provide satisfactory control of ALS-resistant weed biotypes. Tank-mixtures with herbicides having other modes of action will be needed to control these species. Labeled tank-mix partners include: atrazine, Beacon, dicamba, Distinct, Exceed, Harness, Hornet WDG, Marksman, NorthStar, Prowl, Spirit, Surpass, TopNotch, and Tough. *PRECAUTIONS* that should be observed include: certain corn hybrids are sensitive to Option, so consult seed company hybrid sensitivity charts; do not apply Option in the same season if Counter, Dyfonate, or Thimet was used; do not make foliar applications of an organophosphate insecticide within 7 days of a Option application; replant intervals for Option are 7 days for corn, 14 days for soybean, and 60 days for all other crops; the preharvest interval for Option is 70 days for corn grain and 45 days for corn forage.

### Dow AgroSciences LLC

**GF-887 5.4L** (active ingredient glyphosate). Registration of GF-887 is expected the third quarter of 2003. GF-887 is a higher load glyphosate formulation that contains a surfactant. GF-887 is formulated as the isopropylamine salt of glyphosate that contains 5.4 lb ai/gal (4 lb ae/gal). The 24 fluid ounce rate of GF-887 is equivalent to the 32 fluid ounce rate of a 4 lb ai/gal (3 lb ae/gal) glyphosate formulation (i.e., Glyphomax Plus). At this time the trade name for this glyphosate formulation has not yet been determined.

**KEYSTONE 5.25SE** (active ingredients acetochlor and atrazine). Keystone is a recently registered premixture containing 3.0 lb ai/gal of acetochlor (Surpass) and 2.25 lb ai/gal of atrazine. Keystone is formulated as a suspo-emulsion and is used for selective preemergence control of annual grasses, some annual broadleaf weeds, and sedges in field corn, production seed corn, silage corn, and popcorn. Keystone may be applied up to 30 days prior to planting (EPP), preplant incorporated (PPI), preemergence (PRE), and early postemergence (EPOS) to corn up to 11 inches tall. Applications rates range from 2.2 to 3.4 quarts per acre depending on soil texture and soil organic matter content. A typical use rate of 2.65 quarts per acre of Keystone is equivalent to applying 2.5 pints of Surpass and 1.5 lb ai of atrazine per acre.

### DuPont Agricultural Products

**CINCH 7.64EC** (active ingredient *S*-metolachlor), **CINCH ATZ 5.5L** (active ingredients *S*-metolachlor and atrazine), and **CINCH ATZ LITE 6L** (active ingredients *S*-metolachlor and atrazine) are new herbicides being marketed by DuPont Agricultural Products. The Cinch herbicides are equivalent formulations to Syngenta's Dual II Magnum, Bicep II Magnum, and Bicep Lite II Magnum.

**CIMARRON 60DF** (active ingredient metsulfuron). Cimarron is registered for use in pastures, rangelands, and Conservation Reserve Program (CRP) acres. Cimarron is used at 0.1 to 1.0 ounces per acre to control broadleaf weeds. Apply Cimarron in the spring or early summer when weeds are less than 4 inches tall and are actively growing. Cimarron contains the same active ingredient as Ally and the

Cimarron label has many of the same precautionary statements as the Ally label.

**STEADFAST 75WDG** (active ingredients nicosulfuron and rimsulfuron). The maximum corn height for Steadfast applications has been increased to 20 inch tall corn or corn exhibiting 7 leaf collars (V7), whichever is more restrictive.

### FMC Corporation

**AIM EW 1.9EW** (active ingredient carfentrazone). Aim EW is a liquid formulation that will replace the Aim 40DF dry formulation. The Aim EW use rate of 0.5 fluid ounce per acre is equivalent to the 0.33 ounce per acre rate of the dry formulation. Aim is labeled for field corn, seed corn, popcorn, corn silage, sweet corn, grain sorghum, soybeans, wheat, barley, and oats.

### Monsanto Company

**ROUNDUP WEATHERMAX 5.5L** (active ingredient glyphosate). Roundup WeatherMax will replace Roundup UltraMax 5L for broadspectrum weed control in Roundup Ready crops and for nonselective weed control in many cropping systems, farmsteads, and CRP acres. Roundup WeatherMax is a higher load glyphosate formulation that contains a surfactant. Roundup WeatherMax is formulated as the potassium salt of glyphosate that contains 5.5 lb ai/gal (4.5 lb ae/gal). The 22 fluid ounce rate of Roundup WeatherMax is equivalent to 32 fluid ounce rate of a 4 lb ai/gal (3 lb ae/gal) glyphosate formulation (i.e., Roundup Ultra).

**YUKON 67.5WDG** (active ingredients halosulfuron and dicamba). Yukon is a premixture of 12.5% halosulfuron and 55% dicamba that was registered in 2002 for use in field corn, field corn grown for seed, and grain sorghum. The common use rate of Yukon is 4 ounces per acre, which delivers ⅔ ounce per acre of Permit and 4 fluid ounces per acre of Banvel. However, it can be applied up to 8 ounces per acre to control larger weed species in corn (6 ounce maximum rate for sorghum). Applications of Yukon must include either a non-ionic surfactant or a crop oil concentrate, but not both. A nitrogen fertilizer (UAN or AMS) may be added to the spray solution, however it is not required. Two applications of Yukon may be applied to corn per year with a total application not to exceed 8 ounces per acre. Yukon can be applied over-the-top or with drop nozzles from spike through 36-inch tall field corn and from the 2-leaf stage to 15-inch tall grain sorghum. Yukon controls both large and small seeded broadleaf weeds, with the added benefit of yellow nutsedge control. Since Yukon contains dicamba, special precautions need to be taken when applications are made near dicamba-sensitive species.

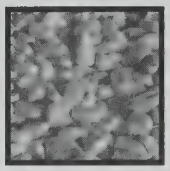
### Syngenta Crop Protection, Inc.

**CALLISTO 4SC** (active ingredient mesotrione). The Callisto rotation restrictions for alfalfa, dry beans, snap beans, peas, sugarbeets, and cucurbits have been changed to 18 months.

**LUMAX 3.95L** (active ingredients *S*-metolachlor, mesotrione and atrazine). Lumax is a recently registered premixture containing 2.68 lb ai/gal of *S*-metolachlor (Dual II Magnum), 0.268 lb ai/gal of mesotrione (Callisto), and 1.0 lb ai/gal of atrazine. Lumax is a selective preemergence herbicide that controls annual grasses, annual broadleaf weds, and sedges in field, seed, and silage corn. Lumax may be applied up to 10 days prior to planting (EPP), PRE, and EPOS up to corn 5 inches tall. Applications rates range from 2.65 to 3.0 quarts per acre depending on soil texture and soil organic matter content. A typical use rate of 3.0 quarts per acre of Lumax is equivalent to applying 2 pints of Dual II Magnum, 6.4 fluid ounces of Callisto, and 0.75 lb ai of atrazine per acre.

### Valent

**PHOENIX 2EC** (active ingredient lactofen). Phoenix is a new formulation of lactofen, which is the active ingredient in Cobra. Phoenix contains 2 pounds per gallon of lactofen plus an adjuvant system. Use rates range from 8 to 12.5 fluid ounces per acre, and applications should include 0.125 to 0.25% v/v nonionic surfactant. A crop oil concentrate (COC) may be used at 1 pint per acre if weeds are under stress due to hot and dry conditions. The addition of a COC will cause soybean leaf burn similar to Cobra. Phoenix with a non-ionic surfactant will also cause some leaf bronzing or speckling, however it may not be to the same extent as Cobra. The rainfastness of Phoenix is 2 hours compared with Cobra's ½ hour.



# PRODUCT UPDATE IN INSECT MANAGEMENT

**Kevin L. Steffey and Michael E. Gray**

This proceedings article is an overview of field crop insect-control products that have been registered recently or are pending registration. Efficacy data are not presented. A handout that includes efficacy data complied from several sources will be distributed at the conference.

The most recently registered insect-control products and products pending registration can be categorized as follows:

- "Conventional" insecticide, i.e., insecticides formulated to be applied by farmers or commercial applicators
- Insecticidal seed treatments
- Transgenic crops modified to express insecticidal proteins

Some of the properties and intended uses for products within each of these categories are discussed. The companies that manufacture or distribute the products are listed alphabetically within each category, and the products are listed alphabetically within each company.

The inclusion of target insects and time of application within article does not necessarily represent a recommendation by entomologists at the University of Illinois. For example, we seldom make specific recommendations for use of soil insecticides for control of seedcorn maggot. For specific recommendations from the University of Illinois, consult current issues of the *Illinois Agricultural Pest Management Handbook* and the *Pest Management & Crop Development Bulletin.*

## CONVENTIONAL INSECTICIDES

Although much of the recent focus on insect control in field crops has been on insecticidal seed treatments and transgenic crops, a few conventional insecticides have been registered in recent years, and the label of another insecticide has expanded recently to include more crops. The following list does not include new formulations of products that have been registered for several years (e.g., Aztec 4.67G and Fortress 2.5G).

### Bayer CropScience

**BAYTHROID 2** (active ingredient cyfluthrin). Baythroid 2, a pyrethroid insecticide, has been registered for use against insect pests of alfalfa and sorghum since 1997. The United States Environmental Protection Agency (EPA) recently (2002) approved the use of Baythroid 2 against insect pests of corn and soybean. Table 1 provides an abridged list of insect pests for which Baythroid 2 is labeled, with recommended rates of application. Some critical use information is included in the footnotes.

Cyfluthrin, like all pyrethroids, is highly toxic to fish and aquatic invertebrates, so caution should be practiced to avoid drift or runoff into bodies of water. Mammalian toxicity is relatively low:oral $LD_{50}$ values for male and females rats are 1,015 and 826 mg/kg, respectively; and the dermal $LD_{50}$ value for male and female rats is >2,000 mg/kg. Cyfluthrin is very water insoluble (2 ppb). Performance of Baythroid 2 in insecticide efficacy trials has been equivalent to performance of the other pyrethroids—Ambush, Asana, Capture, Mustang, Pounce, and Warrior—used in a similar manner.

**Table 1 ■ Abridged label information for control of insects in corn and soybean with Baythroid 2.**

| Crop | Insects | Rate of application |
|---|---|---|
| Corn[1] | Black cutworm | 0.8–1.6 fl oz/acre |
| | Armyworm, chinch bug, corn earworm, adult corn rootworms, European corn borer, flea beetle, Japanese beetle adults, southern corn leaf beetle, southwestern corn borer, stalk borers, stink bugs, webworms | 1.6–2.8 fl oz/acre |
| | Grasshoppers | 2.1–2.8 fl oz/acre |
| Soybean[2] | Cutworms, potato leafhopper | 0.8–1.6 fl oz/acre |
| | Bean leaf beetle, blister beetles, corn earworm, green cloverworm, Japanese beetle adults, loopers, Mexican bean beetle, stink bugs, woollybear caterpillars | 1.6–2.8 fl oz/acre |
| | Grasshoppers | 2.1–2.8 fl oz/acre |

[1] The preharvest interval is 21 days for grain or fodder. The maximum amount of Baythroid 2 allowed per crop season is 11.2 oz/acre. The maximum number of applications per season is four. Three applications may be applied up to early dent stage. One application may be made between early dent and 21 days before harvest. Baythroid 2 may be applied before, during, or after planting.

[2] The preharvest interval is 45 days. The maximum amount of Baythroid 2 allowed per crop season is 11.2 oz/acre. The maximum number of applications per season is four.

### FMC Corporation

**CAPTURE 2EC AND 1.15G** (active ingredient bifenthrin). Capture 2EC, a pyrethroid insecticide, has been on the market for a few years. It is labeled for use against both soil-inhabiting and foliage-feeding insect pests in several field crops. However, its use list continues to change, and supplemental labels have been issued. Table 2 provides an abridged list of insect pests for which Capture 2EC is labeled, with recommended rates of application. Some critical use information is included in the footnotes.

Capture 1.15G is registered solely for use against soil-inhabiting pests of corn—corn rootworm larvae, cutworms, seedcorn maggot, white grubs, and wireworms. Rates of application range from 3.2 to 8 ounces of product per acre, depending upon target insect and placement. Efficacy data for this formulation of Capture are not abundant.

Bifenthrin, like all pyrethroids, is highly toxic to fish and aquatic arthropods, so caution should be practiced to avoid drift or runoff into bodies of water. Mammalian toxicity is moderate to low, depending upon exposure: the oral $LD_{50}$ value for rats is 262 mg/kg; the dermal $LD_{50}$ value for rabbits is >2,000 mg/kg. Bifenthrin has moderate stability in the soil under aerobic conditions (half-life ranges from 65 to 125 days, depending on soil type). Bifenthrin has a high affinity for organic matter and is not mobile in the soil. There is little potential for movement into groundwater. Performance of Capture 2EC in insecticide efficacy trials has been equivalent to performance of the other pyrethroids—Ambush, Asana, Baythroid, Mustang, Pounce, and Warrior—used in a similar manner. The performance of Capture 2EC against corn rootworm larvae has not been as consistent as Aztec 2.1G, Counter CR, Force 3G, and Lorsban 15G.

**Table 2 ■ Abridged label information [including supplemental labels and 2(ee) recommendations] for control of insects and mites in corn with Capture 2EC.**

| Crop | Insects | Rate of application |
|---|---|---|
| Corn[1] | Cutworms, seedcorn maggot, white grubs, wireworms | 0.15–0.3 fl oz/1,000 ft of row |
| | Corn rootworm larvae | 0.3 fl oz/1,000 ft of row |
| | Black cutworm, seedcorn maggot, white grubs, wireworms | 3–4 fl oz/acre, preplant incorporated[2] |
| | Black cutworm | 2.56 fl oz/acre, preemergence[2] |
| | Armyworm, chinch bug, corn earworm, corn leaf aphid, corn rootworm adults, cutworms, European corn borer, fall armyworm, flea beetles, grasshoppers, Japanese beetle adults, sap beetles, southern corn leaf beetle, southwestern corn borer, stalk borers, stink bugs, webworms | 2.1–6.4 fl oz/acre |
| | Twospotted spider mite | 5.12–6.4 fl oz/acre |

[1] The preharvest interval is 30 days (including grazing). Do not apply more than 0.1 pound of active ingredient per acre per season as an at-plant application. Do not apply more than 0.3 pounds of active ingredient per acre per season including at-plant plus foliar applications.

[2] For use in Illinois south of U.S. Route 136.

**MUSTANG** (active ingredient *zeta*-cypermethrin). Mustang, a pyrethroid insecticide, was registered for use in a number of crops in time for the 2002 season. Table 3 provides an abridged list of insect pests for which Mustang is labeled, with recommended rates of application. Some critical use information is included in the footnotes.

Cypermethrin, like all pyrethroids, is highly toxic to fish and aquatic invertebrates, so caution should be practiced to avoid drift or runoff into bodies of water. Mammalian toxicity is moderate to low, depending upon exposure: the oral $LD_{50}$ value for rats is 234 mg/kg; the dermal $LD_{50}$ value for rats is >2,000 mg/kg. Cypermethrin is rapidly degraded in soil, with a half-life of 2 to 4 weeks. Performance of Mustang in insecticide efficacy trials has been equivalent to performance of the other pyrethroids—Ambush, Asana, Baythroid, Capture, Pounce, and Warrior—used in a similar manner.

**Table 3 ■ Abridged label information for control of insects in alfalfa, corn, sorghum, soybean, and wheat with Mustang.**

| Crop | Insects | Rate of application |
|---|---|---|
| Alfalfa[1] | Alfalfa caterpillar, alfalfa weevil, cutworms, meadow spittlebug, potato leafhopper, webworms | 2.4–4.3 oz/acre |
| | Grasshoppers, plant bugs | 3.0–4.3 oz/acre |
| Corn[2] | Cutworms | 0.16 fl oz/1,000 ft of row |
| | Cutworms | 1.4–3.0 oz/acre |
| | Corn rootworm adults, European corn borer, flea beetles, grasshoppers, hop vine borer, Japanese beetle adults, sap beetles, southern corn leaf beetle, southwestern corn borer, stalk borer, stink bugs, webworms | 2.9–4.3 oz/acre |
| | Armyworm, chinch bug, fall armyworm | 3.4–4.3 oz/acre |
| | Corn earworm | 1.9–4.3 oz/acre |
| Sorghum[3] | Cutworms, sorghum midge | 1.4–4.3 oz/acre |
| | Corn earworm, webworms | 1.9–4.3 oz/acre |
| | Chinch bug, grasshoppers | 3.4–4.3 oz/acre |
| Soybean[4] | Cutworms, thistle caterpillar | 1.4–4.3 oz/acre |
| | Bean leaf beetle | 2.4–3.4 oz/acre |
| | Blister beetles, corn earworm, green cloverworm, Japanese beetle adults, Mexican bean beetle, potato leafhopper, soybean aphid, woollybear caterpillars | 3.0–4.3 oz/acre |
| | Grasshoppers, loopers, stink bugs | 3.4–4.3 oz/acre |
| Wheat[5] | Armyworm, cereal leaf beetle | 1.9–4.3 oz/acre |
| | Grasshoppers | 3.4–4.3 oz/acre |

[1] Do not make applications less than 7 days apart. A maximum of 0.05 pound of active ingredient per acre may be applied per cutting and a maximum of 0.15 pound of active ingredient per acre per season. Applications may be made up to 3 days of cutting.

[2] The preharvest interval is 30 days for grain and fodder and 60 days for forage (silage). Do not apply more than 0.20 pound of active ingredient per acre per season, including at-planting plus foliar applications.

[3] The preharvest interval is 14 days for grain and stover and 45 days for forage. Do not make applications less than 10 days apart. Do not apply more than 0.25 pound of active ingredient per acre per season.

[4] The preharvest interval is 21 days. Do not graze or harvest treated soybean forage, straw, or hay for livestock feed. Do not make applications less than 7 days apart. Do not apply more than 0.3 pound of active ingredient per acre per season.

[5] The preharvest interval is 14 days for grain, forage, and hay. Do not make applications less than 14 days apart. Do not apply more than 0.25 pound of active ingredient per acre per season.

### Dow AgroSciences LLC

**TRACER 4SC** (active ingredient spinosad). Tracer is in a new class of insecticides—Naturalytes. Spinosad (also the active ingredient of SpinTor, labeled for some fruits and vegetables) is a fermentation-derived insecticide from the actinomycete bacterium *Saccharopolyspora spinosa*. Tracer has been on the market for a couple of years; its primary targets are in the insect order Lepidoptera, e.g., armyworm and European corn borer. Table 4 provides an abridged list of insect pests for which Tracer 4SC is labeled, with recommended rates of application. Some critical use information is included in the footnotes.

Spinosad is only slightly toxic to aquatic organisms. Mammalian toxicity is extremely low with an $LD_{50}$ value for female rats of >5,000 mg/kg. Tracer has a half-life in soil of 9 to 17 days. Its mode of action is different from the mode of action of organophosphates, carbamates, and pyrethroids. Spinosad causes persistent activation of nicotinic acetylcholine receptors by a distinct and novel mechanism. The performance of Tracer 4SC against caterpillar pests in corn, sorghum, soybean, and wheat has been good.

**XDE-225** (active ingredient gamma-cyhalothrin). This pyrethroid insecticide, which is closely related to Warrior (active ingredient lambda-cyhalothrin), is under development and not yet registered for use. Its properties and performance are similar to those of Warrior, although the target use rate is lower.

## INSECTICIDAL SEED TREATMENTS

The seed treatments discussed in this section are those that are applied to the corn seeds before they are bagged. They are not to be confused with hopper-box seed treatments (e.g., Agrox and Kernel Guard) applied to the seed just before planting.

Insecticidal seed treatments for control of several soil-inhabiting insects in corn have become legitimate alternatives to granular and liquid soil insecticides. In general, performance of seed treatments for control of corn rootworm larvae in insecticide efficacy trials has not been as consistent as performance of Aztec, Counter, and Force. When infestations of corn rootworm larvae are high, seed treatments may not provide acceptable control. However, all of the seed treatments provide good protection of the seed against wireworms and seedcorn maggots. Efficacy data for the seed treatments against other soil-inhabiting insects in corn are not abundant. Therefore, some of the label claims are based upon results from only a few research trials.

### Bayer CropScience (and Gustafson LLC)

**CLOTHIANIDIN** (active ingredient; trade name undetermined). This nicotinoid insecticide, which is closely related to imidacloprid (active ingredient of Gaucho and Prescribe), is under development and not yet registered for use on corn. Its properties are similar to those of imidacloprid, e.g., it is systemic. Its performance against corn rootworm larvae in efficacy trials has been slightly better than the performance of Prescribe. It is likely that insecticidal seed treatments with clothianidin as the active ingredient will replace Gaucho and Prescribe in the marketplace.

### Gustafson LLC

**GAUCHO** (active ingredient imidacloprid). Gaucho is the trade name for the low rate of imidacloprid (0.16 mg of active ingredient per seed) intended for protection of the seed against seedcorn maggot and wireworms. Because of its systemic activity, Gaucho also controls flea beetles through the 1-leaf stage of corn seedling growth. The label also indicates reduction of feeding damage by white grubs during emergence and seedling stages. However, there are limited efficacy data for this product against white grubs. Gaucho is available on a very large range of corn hybrids sold by many seed companies. The list of companies that offer Gaucho-treated corn seed is available at http://www.seedappliedinsecticide.com/where.html.

**PRESCRIBE** (active ingredient imidacloprid). Prescribe is the trade name for the high rate of imidacloprid (1.34 mg of active ingredient per seed) labeled for protection of subterranean parts of corn plants against corn rootworm larvae, grape colaspis, seedcorn maggot, white grubs, and wireworms. Because of its systemic activity, Prescribe also controls flea beetles through the fifth true-leaf stage of development. Efficacy data for control of grape colaspis and white grubs are not abundant. Prescribe is available on selected corn hybrids sold by several seed companies. The list of companies that offer Prescribe-treated corn seed is available at http://www.seedappliedinsecticide.com/where.html.

### Syngenta Crop Protection, Inc.

**CRUISER** (active ingredient thiamethoxam). This nicotinoid insecticide, which is closely related to clothianidin, was registered for use on field, pop, seed, and sweet corn in October 2002. The rates applied to corn seed will be a minimum of 0.125 mg of thiamethoxam per kernel to a maximum of 0.8 mg (field, pop, seed, and sweet corn) or 1.4 mg (field corn only) of

**Table 4 ■ Abridged label information for control of insects and mites in corn, sorghum, soybean, wheat, barley, rye, and oats with Tracer 4SC.**

| Crop | Insects | Rate of application |
|---|---|---|
| Corn[1] | Armyworm, European corn borer, fall armyworm | 1-3 fl oz/acre |
| | Corn earworm, southwestern corn borer | 2-3 fl oz/acre |
| Sorghum[2] | Corn earworm, webworms | 1.5-3.0 fl oz/acre |
| Soybean[3] | Loopers, green cloverworm | 1-2 fl oz/acre |
| | Corn earworm, woollybear caterpillars | 1.5-2.0 fl oz/acre |
| Wheat, barley, rye, oats[4] | Armyworm, cereal leaf beetle | 1-3 fl oz/acre |

[1] The preharvest interval is 7 days for forage and 28 days for grain or fodder. Do not apply more than 6 fl oz per acre per year.

[2] The preharvest interval is 7 days for grain or fodder and 14 days for forage. Do not apply more than 14.4 fl oz per acre per year.

[3] The preharvest interval is 28 days. Do not feed treated forage or hay to meat or dairy animals. Do not apply more than 6 fl oz per acre per year.

[4] The preharvest interval is 21 days for grain or straw and 14 days for forage or hay. Do not apply more than 9 fl oz per acre per year.

thiamethoxam per kernel. Depending upon the rate of application, Cruiser will provide early season protection of seedlings against injury by chinch bug, flea beetles, seedcorn maggot, southern corn leaf beetle, white grubs, and wireworms. The label also claims suppression of cutworms at all rates of application. The higher rates of application (1.125 to 1.4 mg of thiamethoxam per kernel, for field corn only) will provide corn rootworm protection in light-to-moderate infestations and suppression of cutworms. The performance of Cruiser against corn rootworms in insecticide efficacy trials has been similar to the performance of Prescribe. Efficacy data regarding control of the other insects listed on the label are not abundant.

The properties of thiamethoxam are similar to those of clothianidin, e.g., it is systemic. Thiamethoxam is significantly more water soluble than imidacloprid, which can be a boon or a bane, depending upon environmental and soil conditions.

Commercialization of Cruiser will make the seed treatment market more competitive. At 0.125 mg of thiamethoxam per seed, Cruiser will compete with Gaucho. At 1.25 to 1.4 mg of thiamethoxam per seed, Cruiser will compete with Prescribe. However, the availability of corn hybrids treated with Cruiser was not known at the time this article was prepared.

**ProShield Technology with Force ST** (active ingredient tefluthrin). ProShield Technology with Force ST was the first seed treatment on the market to claim control of corn rootworms. Other insects on the Force ST label include seedcorn maggot, white grubs, and wireworms. As with other seed treatments, efficacy data for control of most of the secondary insect pests of corn are not abundant. ProShield Technology with Force ST is available on a limited number of corn hybrids.

## TRANSGENIC CROPS

Corn hybrids genetically transformed to resist European corn borer, southwestern corn borer, and a few other pest Lepidoptera were commercialized for the first time in 1996. Since 1997, the market for Bt corn has grown, ebbed, and then grown again, primarily responding to export concerns, densities of European corn borer, and media uproar. Regardless, Bt corn has become part of our agricultural landscape in North America and offers significant benefits when densities of European or southwestern corn borers reach economic levels.

Although several transgenic corn events for insect resistance have been commercialized, only one of them (Monsanto's event MON810; trade name YieldGard Corn Borer) was available through 2002. A new transgenic event for corn borer resistance will be available in several corn hybrids for the first time in 2003. In addition, Monsanto Company has applied for registration for a transgenic event for corn rootworm resistance. These latter two transgenic events are discussed.

### Dow AgroSciences LLC

**Herculex I Insect Protection** (expresses the Cry1F insecticidal protein). Herculex I products contain a different protein than YieldGard Corn Borer products, which contain the Cry1Ab protein. Herculex I hybrids will compete directly with YieldGard Corn Borer hybrids for control of European and southwestern corn borers. Other pest Lepidoptera controlled by Herculex I include black cutworm, corn earworm (suppression), and fall armyworm. Herculex I and YieldGard Corn Borer are equivalent in their efficacy against European and southwestern corn borers.

Herculex I is fully approved in the United States for food and feed, and full approval was received in Japan in 2002. However, Herculex I currently is not approved for export to Europe. Herculex I will be available commercially in Mycogen Seeds hybrids for the 2003 growing season. The insect resistance management requirements for Herculex I in Illinois are identical to the insect resistance management requirements for YieldGard Corn Borer—minimum of 20% of acres for non-Bt corn refuge, planted within ½ mile of fields with Bt corn hybrids.

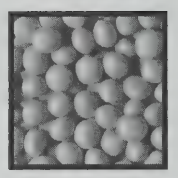
### Monsanto Company

**YieldGard Rootworm** (expresses the Cry3Bb1 insecticidal protein). This event (Monsanto's MON863) has been submitted to U.S. governmental agencies (EPA, United States Department of Agriculture, and Food and Drug Administration) and to equivalent Canadian agencies for approval for registration. It also has been under review in Japan and Europe. If commercialized, YieldGard Rootworm hybrids will be the first transgenic corn hybrids registered for control of corn rootworm larvae.

In late May of 2002, a technical committee (NCR-46) of research and extension entomologists, along with selected cooperators, sent a letter to the EPA offering their support for a conditional registration of transgenic event MON 863 for rootworm control.

Transgenic corn that expresses the Cry3Bb1 protein has been evaluated for its ability to protect roots against rootworm larval feeding by Monsanto Company scientists and university entomologists, including entomologists at the University of Illinois. If transgenic corn for rootworm control becomes commercially available (after approval by EPA), a significant reduction in the use of soil insecticides is likely. Rapid acceptance of transgenic corn for rootworm control is anticipated.

It is possible that the EPA will issue a conditional registration for the 2003 growing season, allowing some producers within the United States to begin using transgenic hybrids for management of corn rootworms. For now and during an interim registration period, the NCR-46 committee is supportive of a proposed 20% refuge of nontransgenic corn that must be placed within or adjacent to the field in which transgenic corn is planted. During the next several years, entomologists will continue to collect important data that can be used to improve resistance management plans.



# PRODUCT UPDATE IN DISEASE MANAGEMENT

**Dean Malvick**

This proceedings paper and the accompanying presentation in January will provide a brief update on products for management of diseases affecting field crops in Illinois. Management of most field crop diseases is based primarily on disease resistance and agronomic practices such as rotation. Foliar fungicides are important for control of some important leaf and stem diseases in certain situations, especially in seed production fields. Bactericides and nematicides are rarely used in Illinois for field crops. Fungicidal seed treatments are widely used to control seed and seedling diseases of corn, soybean, wheat and alfalfa, often in combination with disease resistant cultivars and hybrids. Compared to the numerous new products and product labels for insect and weed management, there are relatively few new products available for disease management. A few new products have become available recently, however, and there are many effective products that are not new. For more specific information on fungicides and other products for management of field crop diseases—see the 2003 issue of the *Illinois Agricultural Pest Management Handbook.*

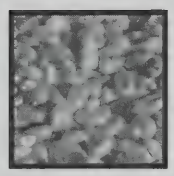
Many field crop diseases are managed economically with resistant hybrids and cultivars. New disease resistant corn, soybean, wheat, and alfalfa hybrids and cultivars will be released by numerous seed companies this year. Steady progress is being made in developing improved resistance to many of the important field crop diseases in Illinois, e.g., sudden death syndrome and soybean cyst nematode. Seed dealers and company representatives are the best source of information for the improved disease resistance that will be available in new cultivars and hybrids for 2003.

A variety of different fungicides are available for control of foliar diseases of corn. Many of these are effective when applied in a timely manner. One new product, Stratego® was registered in 2002 by Bayer Crop Protection for control of rust, gray leaf spot, eye spot, and the 'Helminthosporium' leaf blights (southern corn leaf blight, northern corn leaf spot, and northern corn leaf blight). The two active ingredients in Stratego are propiconazole (the same active ingredient in Tilt® from Syngenta and PropiMax™ EC from Dow AgroSciences) and trifloxystrobin (similar in chemistry and mode of action to the active ingredient azoxystrobin in Quadris® from Syngenta). Stratego is labeled for application to corn between the V4 to after silking growth stages.

The fungicidal seed treatment category is an active area where new products are under development and registration for disease control. Dividend Extreme™ is a seed treatment that was registered by Syngenta in 2002 for control of wheat diseases. It contains two active ingredients, Difenoconazole and mefenoxam (the active ingredient found in ApronXL® from Syngenta). Dividend Extreme is labeled for control of approximately 17 different wheat diseases. Refer to the product label for diseases controlled and application rates for different diseases under different situations.

A relatively new fungicidal active ingredient for seed treatment is azoxystrobin. One seed treatment product recently labeled for soybeans containing azoxystrobin is SoyGard™ from Gustafson LLC. In addition to axozystrobin, SoyGard contains metalaxyl, (the active ingredient in Allegiance FL™ and Apron FL from Gustafson). SoyGard is labeled

for control of *Rhizoctonia* and *Pythium* spp. that cause seed and seedling decay of soybeans. New seed treatment products containing azoxystrobin are under development and may be labeled soon for control of seed and seedling diseases of corn and soybeans. Additional information on products for management of field crop diseases will be presented at the conference.



# HERBICIDE FATE AS INFLUENCED BY THE SOIL ENVIRONMENT

**F. William Simmons**

Herbicides with soil activity are still an important component of weed control in corn and soybean. These herbicides may include both PRE applied herbicides and POST applied herbicides with soil activity. The interaction of soil properties, water, and application timing affects the fate and behavior of herbicides, crop response, and potential for carryover. This article discusses the following topics: the basics of soil interactions with herbicides; the value of residual control in total POST systems; behavior of "new herbicides" in the soil; carryover potential as affected by herbicide, soil, and climatic conditions; and time-dissipation relationships for fall-applied herbicides.

Soils contain the organic matter and clay particles that control herbicide sorption and water relations and provide the environment that influences microbial activity. The primary herbicide loss pathways in soil are microbial breakdown and chemical breakdown, largely driven by reactions with water. The affects of soil temperature and moisture on herbicide degradation are straightforward in that degradation mechanisms that involve microorganisms operate best at optimum biological growth conditions. In addition, nonbiological chemical reactions are also typically enhanced with increased temperature. Water is essential for microbial activity and increases aerobic processes up to the point that saturation occurs and gas transfer with the atmosphere is hampered.

Soil texture and organic matter content have a surprisingly small effect on carryover because the differences in water and nutrient availability are often counterbalanced by the difference in herbicide adsorption. Thus, a fertile soil, rich in organic matter may promote faster degradation of a herbicide but also have less available to degrade based on its greater adsorption sites.

Soil pH is important in affecting the stability of some herbicides and herbicide families. High soil pH associated with calcitic soils, over-liming, or proximity to limestone gravel lanes may reduce herbicide degradation and increase carryover, which may be important for trains and some sulfonylureas. Hydrolysis, an important breakdown mechanism, slows significantly at soil pH values near 7.0.

Biopersistence, or the ability of the parent compound to exist in the soil, is an important feature of soil-applied and some postemergence herbicides and determines the suitability of early preplant applications, residual weed control, and threat of off-site loss to surface or groundwater. To optimize the application timing of soil-applied herbicides, a balance between persistence and requirement for rainfall needs to be considered.

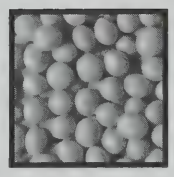
The soil-applied Acetamide market in corn is still a significant and competitive marketplace where performance profiles across application timings determine use and market share. In the past few years, several new herbicides have been introduced: Define (flufenacet) by Bayer Corporation, Degree by Monsanto (encapsulated acetochlor), and most recently, several formulations containing mesitrione (Callisto and Lumax). Dual Magnum is the active isomer of metolachlor and allows for a lower use rate than the "old" Dual. BASF has also purified an active isomer of dimethenamid (Frontier/Outlook) that allows its use rate to be lowered while obtaining the same efficacy. These developments are the most recent in the marketplace. Future changes in the use

patterns of these herbicides may occur in transgenic corn, in mixes with isoxaflutole and similar herbicides, and in formulations that allow post application of these herbicides.

Herbicide persistence is an important property of soil-applied herbicides and some postemergence herbicides that allows for extended weed control. When the herbicide remains unaltered in the soil during the crop season of application it is an advantage. If a herbicide remains in the soil and is present when a rotational (and susceptible) crop is planted the persistence causes herbicide carryover. Most herbicides *do not* carryover. Degradation rates in the soil under normal environmental conditions typically reduce herbicide concentrations to sublethal levels for rotational crops. Some herbicides have additional safety in that they are not injurious to rotational crops.

Shifts in herbicide application timing to earlier applications have put a premium on herbicide persistence to coincide with weed emergence. In a broad sense, the resistance to degradation and downward movement within the soil profile are both important to obtaining satisfactory weed control.

Glyphosate-resistant soybean treated with glyphosate alone do not allow for any residual control of weeds that might germinate after the last POST application is made. What is the value of a residual herbicide either mixed in with glyphosate or applied to the soil at planting? Data are presented that addresses this issue.



# WINTER ANNUAL WEED MANAGEMENT

**Bill Johnson, Christy Sprague, and Ryan Hasty**

## ABSTRACT

Winter annual weed growth has been vigorous and very noticeable across much of the central and southern Corn Belt over the past few years. Because most winter annual weeds have relatively shallow root systems, they do not deplete soil moisture as aggressively as summer annual weeds and any ground cover can reduce moisture evaporation from the soil surface. The result is a wetter field in the early spring, delays in planting and/or need for tillage to control the vegetation and dry the field. Field research was conducted in Missouri and Illinois to evaluate various herbicide combinations and application timings for winter annual weed management. Most of the fall-applied herbicide treatments evaluated provided noticeable suppression of winter weed growth. However, keep in mind that winter weeds tend to be a little less predictable in their growth than summer annuals. The benefit of cleaner fields at planting with fall herbicide applications is highly dependent on spring weather. If spring is relatively dry and planting is accomplished at a "normal" time (late April to mid-May), the appropriate fall-applied herbicide can be used to replace a normal spring burndown treatment. However, if planting is delayed into late May or later because of wet weather, our observation is that a subsequent burndown treatment is needed whether a fall-applied herbicide was used or not. This point is important when planning input costs for next year's crop.

## INTRODUCTION

Interest is growing in the use of fall-applied herbicides to reduce infestations of winter annual weeds in corn and soybean production. Much of this is the result of the market penetration of Roundup Ready soybean (>85% of the soybean acres in Missouri and approximately 75% of the soybean acres in Illinois) and the concurrent reduction of soil-applied herbicide use in soybean. In the past, the residual herbicides commonly used for summer annual weed control in soybean have provided suppression of winter annuals that emerge in the fall. However, their use has declined substantially over the past 5 years. In addition, the past couple of winters have been relatively mild and resulted in extending the growing season for winter vegetation. As a result, winter weed growth has been vigorous and very noticeable across much of the central and southern Corn Belt. Because most winter annual weeds have relatively shallow root systems, they do not deplete soil moisture as aggressively as summer annual weeds and any ground cover can reduce moisture evaporation from the soil surface. The result is a wetter field in the early spring, delays in planting and/or need for tillage to control the vegetation and dry the field. In addition, controlling these weeds in the fall prevents them from producing seed, thereby decreasing the soil seed bank and helping reduce future problems with these species. Fall control of simple perennials, such as dandelion and white cockle, are much more effective than controlling these weeds in the spring. In the fall, food reserves in these perennials are being moved to the roots and can cause complete control of the roots. Additionally, higher

rates of some translocated herbicides (i.e. 2,4-D) can be used in the fall, allowing greater control of perennial weeds such as dandelion.

There are three basic approaches to fall herbicide applications: 1) apply a herbicide with soil residual activity before most of the winter annual weed species germinate; 2) apply a nonresidual herbicide, such as glyphosate, 2,4-D, or Gramoxone, to emerged winter annual, biennial, and perennial weeds while they are relatively small or in the rosette stage; and 3) use a combination of approaches 1 and 2. All of the approaches are striving to reduce the amount of total vegetation that needs to be dealt with in the spring before planting, possibly even eliminating the need for a burndown herbicide application. Although these approaches sound good in theory, the actual results may or may not be as good as expected, in large part due to uncertain weather conditions.

## PROBLEMATIC WINTER WEEDS

Although there are a number of winter annual weeds that commonly infest corn and soybean, the ones considered most problematic at the current time are common chickweed, purple deadnettle, henbit, butterweed, horseweed (marestail), downy brome, and the mustard species (e.g., field pennycress and yellow rocket). Descriptions of these weed species can be found below and color photographs can be found at the following Web sites:

**MISSOURI WEEDS—UNIVERSITY OF MISSOURI**
http://www.psu.missouri.edu/fishel/

**COMMON WEEDS OF NO-TILL CROPPING SYSTEMS**
**Purdue University**
http://www.btny.purdue.edu/Extension/Weeds/NoTillID/NoTillWeedID1.html

**WEED SCIENCE SOCIETY OF AMERICA PHOTO HERBARIUM**
http://www.wssa.net/subpages/weed/herbarium0.html

**COMMON WEED SEEDLINGS OF MICHIGAN**
http://www.msue.msu.edu/msue/iac/e1363/e1363.htm

**Common chickweed** *(Stellaria media)* is a winter annual that can become a perennial in cool, moist areas. Cotyledons are slender, and ovate with a hairy stalk as long as the blade. Young leaves are opposite, smooth, and a light green. Leaves on the upper stem do not have petioles. Common chickweed has a fibrous root system and can form dense, prostrate mats. It has a white flower, reproduces by seed, and can germinate in the early spring and late summer. In shady moist areas, germination can occur throughout the summer. One or two generations can be produced each year.

**HENBIT** *(Lamium amplexicaule)* is a winter annual that emerges from cool, moist soil. Cotyledons are round to oblong with hairy petioles. Young leaves have petioles and are opposite with hair on the upper surface. Stems are square. Leaves on the upper stem are sessile (no petioles). Henbit has a fibrous root system. It has a pink-to-purple flower, reproduces by seed, and germinates in the early spring and fall.

**PURPLE DEADNETTLE** *(Lamium purpuream)* is a winter annual that emerges from cool, moist soil. Cotyledons are round to oblong with hairy petioles. Young leaves have petioles and are opposite with hair on the upper surface. Stems are square. Leaves on the upper stem are sessile (no petioles). It has a fibrous root system. It has a purple flower, reproduces by seed, and can germinate in the early spring and fall. Similar to henbit except that deadnettle leaves are more densely hairy, more triangular, and have petioles on most all of the leaves.

**CRESSLEAF GROUNDSEL/BUTTERWEED** *(Senecio glabellus)* is a winter annual that emerges from cool, moist soil. Leaves are arranged in a basal, purple rosette, and older have long petioles. Older leaves in the rosette do not have lobes. Lobes begin to appear on new growth. Stems are smooth and hollow. It has a yellow flower, reproduces by seed, and germinates in the early spring and late summer.

**HORSEWEED/MARESTAIL** *(Conyza canadensis)* is a winter or summer annual. Cotyledons are oval. Young leaves are egg-shaped with toothed margins. Lower leaves are petioled and form a basal rosette and are covered with hair. Leaves on the upper stem are alternate. It has a short taproot with secondary fibrous roots. It has pink-to-yellow flowers, reproduces by seed, and germinates in the early spring and late summer.

**DOWNY BROME** *(Bromus tectorum)* is a winter or summer annual. The first leaf is linear and opens perpendicular to the ground. Leaves have a membranous ligule that is fringed at the top. Young leaf blades are twisted and have soft, short dense hairs. It has a fibrous root system. It reproduces by seed and can germinate in the early to mid-spring and late summer to mid-autumn.

**ANNUAL BLUEGRASS** (*Poa annua*) is a winter annual or a summer annual. Leaves are smooth and curved upward on the edges towards the tip, creating a canoe shape. It has a membranous ligule, panicle inflorescence, and reproduces by seeds. Germination occurs in the fall to early spring.

**WILD MUSTARD** *(Brassica kaber)* is a winter or summer annual. Cotyledons are kidney or heart-shaped with a distinct indentation at the cotyledon tip. Young leaves are oblong with wavy, toothed margins and occasionally wrinkled surfaces. Lower leaves have relatively long petioles and deep-jagged, lobed blades. Upper leaves become progressively smaller and are not lobed as deeply. Stems are smooth and hollow. It has a slender taproot with fibrous secondary roots. It has a yellow flower; reproduces by seed, and germinates in the late summer, early fall, or spring.

**FIELD PENNYCRESS** *(Thlaspi arvense)* is a winter or summer annual. Cotyledons are bluish green, oval to oblong with the tips curving downward. Young leaves are smooth, round to oval with distinct petioles. Leaves on upper stem clasp the stem and have auricles. Stems are smooth and erect. It has a tap root system. It has a white flower, reproduces by seed, and germinates in the early spring and late summer.

**SHEPHERD'S-PURSE** *(Capsella bursa-pastoris)* is a winter annual. Cotyledons are egg-shaped to rounded and narrowed at the base. Young leaves on the rosette have variable leaf margins. The first leaves are rounded, becoming elongated with age. Older leaves are deeply toothed or lobed with triangular segments. Stems are erect, slender, covered with gray hairs, and usually unbranched. It has a slender, often branched taproot with secondary fibrous roots. It has an inconspicuous white flower, reproduces by seed, and germinates in the late summer, early fall, or early spring.

**YELLOW ROCKET** *(Barbarea vulgaris)* is a winter annual, biennial, or seldom a perennial. Cotyledons are egg-shaped to round on long stalks. Young leaves are rounded, some with a heart-shaped base. Margins are entire or wavy and become distinctly toothed with age. It has a taproot with fibrous secondary roots. It has a bright yellow flower, reproduces by seed, and germinates in the spring and fall.

**DANDELION** *(Taraxacum officanle)* is a perennial with a deep taproot that reproduces by seeds. Leaves are arranged in a basal rosette and lobed with a prominent midrib. Flowers are bright yellow and can be present from early spring to fall.

Over the last couple of years research has been conducted at the University of Missouri and the University of Illinois to examine different approaches to manage a number of these winter weeds in the fall. Below are summaries of some of the research that has been conducted in Missouri and Illinois.

## RESEARCH SUMMARIES FROM THE UNIVERSITY OF MISSOURI

### Soybean—2000

On November 12, 1999, a field experiment was established to examine various residual herbicide treatments for management of winter annual weeds. In addition to the herbicide treatments with residual activity 2,4-D (8 oz/acre) was applied across the entire experimental area. The fall-applied treatments were evaluated for their activity on henbit and chickweed on March 1, 2000. The fall-applied treatments and the evaluations are listed in Table 1.

All treatments except Sencor alone provided 91% or better control of chickweed. Sencor alone provided 76% control of chickweed with the 6-oz rate and 83% control with the 8-oz rate. All treatments provided 93% or greater control of henbit. These preliminary results suggest that the herbicides listed in Table 1

**Table 1 ■ Chickweed and henbit control with fall applied herbicides on March 1, 2000, Missouri.**

| Herbicide | Rate/acre | Chickweed | Henbit |
|---|---|---|---|
| | | % control | |
| Steel | 3 pt | 95 | 93 |
| Steel + Prowl | 3 pt + 1.25 pt | 100 | 95 |
| Python + Sencor | 1 oz + 3.5 oz | 98 | 98 |
| Canopy | 3 oz | 89 | 100 |
| Canopy | 6 oz | 100 | 99 |
| Canopy XL | 4.1 oz | 93 | 98 |
| Canopy XL | 6.8 oz | 91 | 100 |
| Sencor | 6 oz | 76 | 94 |
| Sencor | 8 oz | 83 | 96 |
| LSD (0.05) | | 11 | 4 |

LSD, least significant difference.

would be effective at reducing growth of these two weeds over the winter.

### Soybean—2001

Winter weed control experiments were conducted at Columbia (in central Missouri) and Novelty (in northeast Missouri). The experimental sites were on clay pan soil types (approximately 2.5% organic matter) at University of Missouri Ag Experiment Stations. The treatments were applied in mid-November 2000 after the soil temperatures dropped to less than 50°F. At the time of application, winter vegetation had emerged and 2,4-D was added to all treatments in addition to an application of 2,4-D alone. Winter weed control was evaluated in early March and at planting in May.

**Table 2 ■ Winter weed control for fields rotating into soybean at Columbia, MO, on March 5 and May 15, 2001.**

| Herbicide and Rate/Acre | Henbit | Chickweed | Henbit | Chickweed |
|---|---|---|---|---|
| | March 5 | | May 15 | |
| | % control | | | |
| 2,4-D 1 pt | 50 | 13 | 95 | 78 |
| 2,4-D + Sencor 10 oz | 100 | 100 | 80 | 100 |
| 2,4-D + Python 1 oz + Sencor 4 oz | 100 | 98 | 92 | 96 |
| 2, 4-D + Canopy XL 4.5 oz + Express 0.17 oz | 100 | 98 | 100 | 100 |
| 2, 4-D + Valor 2 oz + FirstRate 0.6 oz | 100 | 88 | 100 | 85 |
| 2, 4-D + Backdraft 4 pt | 99 | 99 | 93 | 100 |
| LSD (0.05) | 4 | 8 | 19 | 20 |

LSD, least significant difference.

At Columbia, 2,4-D alone provided poor control of henbit and chickweed on March 5, but control improved by May 17 (Table 2), probably due because these two weeds had reached maturity and were senescing. Control of henbit and chickweed with all other treatments was 85% or higher.

At Novelty (Table 3), winter weed populations were sparse in March and no observations were recorded. The plots were rated at soybean planting on May 15 and all treatments controlled fleabane 93% or higher with the exception of 2,4-D alone (83%). Annual bluegrass was controlled 93% or higher with all treatments except 2,4-D alone (63%). Dandelion control was somewhat variable. The 2,4-D + Python + Sencor only provided 25% control, whereas all other treatments provided control ranging from 68 to 100%. 2,4-D alone provide similar control as 2,4-D + Sencor, Valor + FirstRate, or Backdraft. 2,4-D + Canopy XL + Express provide greater control of dandelion than 2,4-D alone, 2,4-D + Sencor, and 2,4-D + Valor + FirstRate.

### Corn—2001

The experimental site was on clay pan soil (approximately 2.5% organic matter) at the University of Missouri Ag Experiment Station in central Missouri. The treatments were applied in mid-November 2000 after the soil temperatures dropped to less than 50°F. At the time of application, winter vegetation had emerged and 2,4-D was added to all treatments in addition to an application of 2,4-D alone. Winter weed control was evaluated in early March and at planting in May.

2,4-D alone provided poor control of henbit and chickweed on March 5, but control of henbit improved to 94% by May 4 (Table 4), probably because this weed had reached maturity and was senescing. Control of chickweed was only 20% on May 4 with 2,4-D alone. Control of henbit and chickweed with all other treatments was 85% or higher on March 5 and May 4.

**Table 3 ■ Winter weed control for fields rotating into soybean at Novelty, MO, May 15, 2001.**

| Herbicide and Rate/Acre | Fleabane | Annual bluegrass | Dandelion |
|---|---|---|---|
| | May 15 | | |
| | % control | | |
| 2,4-D 1 pt | 83 | 65 | 78 |
| 2,4-D + Sencor 10 oz | 93 | 93 | 78 |
| 2,4-D + Python 1 oz + Sencor 4 oz | 93 | 88 | 25 |
| 2, 4-D + Canopy XL 4.5 oz + Express 0.17 oz | 100 | 100 | 100 |
| 2, 4-D + Valor 2 oz + FirstRate 0.6 oz | 100 | 100 | 68 |
| 2, 4-D + Backdraft 4 pt | 100 | 100 | 84 |
| LSD (0.05) | ns | 29 | 31 |

LSD, least significant difference.

On May 15, we evaluated the plots for giant foxtail and common waterhemp control. Control of these weeds was 82% or less, indicating that supplemental weed control practices would have been required to improve weed control enough to attain maximum yield potential.

**Table 4 ■ Weed control with fall applied herbicides at Columbia, MO, in 2001.**

| Herbicide and Rate/Acre | Henbit | Chickweed | Henbit | Chickweed | Giant Foxtail | Common Waterhemp |
|---|---|---|---|---|---|---|
| | March 5 | | May 4 | | May 15 | |
| | % control | | | | | |
| 2,4-D 1 pt | 65 | 54 | 94 | 20 | 0 | 0 |
| 2,4-D + Basis 0.5 oz | 86 | 89 | 98 | 98 | 73 | 33 |
| 2,4-D + Princep 1.1 lb | 86 | 95 | 95 | 93 | 82 | 82 |
| 2,4-D + Basis + Princep | 95 | 91 | 100 | 98 | 73 | 65 |
| 2,4-D + Express 0.33 oz + Princep | 94 | 93 | 99 | 100 | 81 | 96 |
| 2,4-D + Python 1 oz + Sencor 5 oz | 94 | 93 | 98 | 94 | 69 | 81 |
| LSD (0.05) | 15 | 12 | 15 | 12 | 23 | 29 |

LSD, least significant difference.

## RESEARCH RESULTS FROM THE UNIVERSITY OF ILLINOIS

### Winter annual weed control

During fall 1999 and 2000, an experiment was conducted at four locations in Illinois to examine the efficacy of fall-applied soybean herbicides. The locations selected were Dekalb, Urbana, Brownstown, and Altamont, which represent a good north-to-south gradient, as well as some diversity in weed species. At these four locations, fall herbicide applications were made in mid-November. The herbicides we included were Canopy (3.0 and 7.0 oz/acre), Canopy XL (2.5 and 6.8 oz/acre), and Sencor (4.0 and 10.0 oz/acre), all with and without glyphosate + 2,4-D. Glyphosate (Roundup Ultra) + 2,4-D (1.5 pt + 0.5 pt) also was applied alone to see how this treatment would work without a residual herbicide. As expected at the outset, results with these fall applications were variable at soybean planting. What we found out was that fall herbicide applications seemed to be more suited to the southern regions of the state where winter annual weed growth was much more prevalent. In many cases, the higher rates of these herbicides out performed the lower rates; however, this outcome could be overcome with the addition of glyphosate and 2,4-D to these treatments. In comparing just the residual treatments Canopy at both rates and the high rate of Canopy XL were the most consistent at controlling common chickweed, annual bluegrass, purple deadnettle, cressleaf groundsel (butterweed), and shepherd's-purse. Across years and locations, the addition of glyphosate and 2,4-D added consistency to winter annual weed control. Glyphosate and 2,4-D alone provided excellent control of a variety of winter annual weeds, with the exception of species that can germinate application (annual bluegrass, horseweed, and cressleaf groundsel). Early germinating summer annual species (e.g., giant ragweed, common ragweed, and common lambsquarters) proved to be the hole in the armor for this particular treatment. In many cases, there was less weed growth in the untreated plots compared with the glyphosate + 2,4-D plots at planting due to winter annual species suppressing the growth of the summer annuals.

### Fall applications based on soil and air temperature

Last fall, two experiments were initiated to test the effect of residual application timing based on soil temperature and existing winter annual weed control based on air temperature. The soil temperature study consisted of Canopy XL + Express (4.5 + 0.17 oz/acre), Python + Sencor (1.25 + 3.0 oz/acre), and Backdraft (4 pt/acre) applied to soil temperatures ranging from 65 to 30°F. Results from the first year did not reveal dramatic differences in summer annual weed control based on application timing.

The second experiment, fall burndown based on air temperature, consisted of Gramoxone Max (26 oz/acre), Canopy XL + Express (4.5 + 0.17 oz/acre), and Roundup Ultra Max + 2,4-D (26 + 16 oz/acre). These treatments were selected to represent a range in the speed of control. The trial area was heavily infested with common chickweed and the applications began in early November after germination was complete. Air temperatures at the different applications ranged from 65 to 25°F (daytime high temperatures). Fall ratings 14 days after treatment showed a linear

response to temperature; weed control efficacy increased with air temperature. Canopy XL + Express and Roundup Ultra Max + 2,4-D controlled greater than 95% of common chickweed 15 days before planting across all applications. Gramoxone Max had an optimum timing of 45°F where control was greater than 90%. Based on 1 yr of data it seems that if Gramoxone Max is applied too early, common chickweed can recover from the application. If it is applied too late, common chickweed is hardened off by frost and control is compromised.

### Dandelion control

A field study focusing on dandelion control was established in fall 2000 in Urbana. The main objectives were to compare 2,4-D formulations, application timings (fall vs. spring), and product use rates. Overall, the ester formulation was superior to the amine formulation for dandelion control (Table 5).

**Table 5 ■ Dandelion control at planting with fall and spring applications, Urbana, IL, 2001.**

| Herbicide | Rate/Acre | Fall | Spring |
|---|---|---|---|
| | | April 11 | |
| | | % control | |
| 2,4-D Ester | 1 pt | 71 | 55 |
| 2,4-D Amine | 1 pt | 75 | 62 |
| 2,4-D Ester | 1 qt | 96 | 68 |
| 2,4-D Amine | 1 qt | 80 | 60 |
| 2,4-D Ester | 1.5 qt | 99 | 82 |
| 2,4-D Amine | 1.5 qt | 96 | 65 |
| LSD (0.05) | – | 16 | |

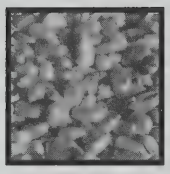
LSD, least significant difference.

The effect of application timing was significant; fall-applications controlled dandelion much more effectively than the early preplant applications. Application rate also played a significant role in dandelion control, the 1.0 qt/acre rate of 2,4-D ester provided the greatest control and was significantly greater than the 1 pt/acre rate.

## CONCLUSIONS

So, how do you know whether fall herbicide applications are suitable for your farming operation? These applications are most effective on fields where winter annuals have been a problem in the past. If spring herbicide treatments have been effectively controlling these species and they do not seemto be increasing, there may be little or no benefit to fall herbicide applications to these fields.

In general, many of the fall-applied herbicide treatments evaluated provided a noticeable suppression of winter weed growth. However, keep in mind that winter weed growth tends to be a little less predictable than summer annual weed growth. The benefit of fall-applied herbicides in having a cleaner field at planting is highly dependent on spring weather. If spring is relatively dry and planting is accomplished at a normal time (late April to mid-May), the appropriate fall-applied herbicide can be used to replace a normal spring burndown. However, if planting is delayed into late May or later because of wet weather, our observations from 2 yr of research is that a subsequent burndown will be needed whether a fall-applied herbicide was used or not.

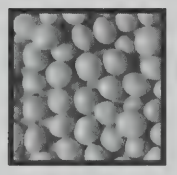


# "CSI: CROP SYMPTOM INVESTIGATIONS"

**Dave Feltes and Dennis Bowman**

On first thought, you might not think crop troubleshooting and crime scene investigation have much in common; however, there are many similarities. Interviewing witnesses and suspects is a lot like collecting field history and background information from growers, applicators, and input suppliers. They often hold the "key" to the puzzle and either inadvertently or intentionally do not supply it until asked specific questions. The evidence or symptoms must be analyzed carefully. Looking for patterns or symptoms that narrow the list of "suspects." Taking what you know about the "modus operandi" of crop pests (the life cycle and habits of insects, weeds, and diseases) and comparing that with the set of symptoms present in the field. You also may need to carefully collect "evidence" for laboratory analysis or if necessary, to prove your case in court. Plant samples, tissue samples, soil samples, and pictures can be used to document your case. Often the perpetrator has fled the scene and the case must be based on circumstantial evidence.

Although there are differences between crop troubleshooting and crime solving, they do require many of the same skills.



# DRIFT REDUCTION TOOLS AND TECHNIQUES

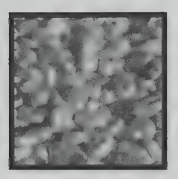
**Mark F. Mohr and Robert E. Wolf**

Proper application timing is critical for getting the best biological results (efficacy) when applying crop protection products. Application timing also can influence off-target spray drift and damage to the environment. Off-target spray drift is a major source of concern. When spraying pesticides, there is always a chance some product will escape from the target area. Spray drift is a concern because it removes the chemical from the intended target, making it less effective and depositing it where it is not wanted. Off-target pesticide becomes an environmental pollutant that can injure susceptible vegetation, damage wildlife, and contaminate water supplies. Although spray drift cannot be completely eliminated, proper equipment (e.g., nozzles) and spraying techniques can help maintain spray drift deposits within acceptable limits.

Using application techniques and technologies that reduce spray drift improves the performance of spray materials, benefits the environment, and is cost-effective. One practice used alone may not suffice. The best option would be to include as many or all of the techniques as a regular part of your spray program (Table 1). As an applicator, do not put yourself into a position where you need to spray "right now." Schedule and plan so that you have an option not to spray when the wrong weather conditions exist. Make sure the customer understands the importance of minimizing drift. Minimizing spray drift is in the best interest of everyone. Do your part to keep agrichemical applications on target.

**Table 1 ■ Recommended techniques for reducing particle drift.**

| Recommended technique | Explanation |
|---|---|
| Select a nozzle to increase droplet size | Use droplets as large as practical to provide necessary coverage |
| Use lower end of pressure range | Higher pressures generate many more small droplets with greater drift potential |
| Lower boom height | Wind speed increases with height; boom height lowered by a few inches can reduce off-target drift<br>High field travel speeds may result in an unstable boom, leading to high boom positions and drift potential |
| Increase nozzle size (resulting in higher application volumes) | Larger capacity nozzles can reduce the amount of spray depositing off target; also, more gallons per acre help maintain spray coverage on the target |
| Avoid high application ground speeds or major speed changes across the field | Rate controllers adjusting to speed changes may result in pressure adjustments causing droplet size variability; rapid speed increases may create high pressure, resulting in more drift potential |
| Avoid high wind speeds | More of the spray volume moves off target as wind increases<br>Wind currents can drastically affect spray droplet deposition<br>Structures (windbreaks, tree lines, buildings, hills, and valleys) drastically affect wind currents |
| Avoid light and variable winds | Light winds tend to be variable in direction, making it hard to identify the sensitive downwind areas |
| Do not spray when the air is completely calm | Calm air generally occurs in early morning or late evening and may indicate the presence of a temperature inversion; calm air reduces air mixing and leaves a spray cloud that may move slowly downwind at a later time |
| Consider using buffer zones/no-spray zones; be able to identify sensitive areas | Leave a buffer zone/no-spray zone if sensitive areas are downwind; spray buffer zone when wind changes to a favorable direction |
| Consider using new technologies | Consider using drift reduction nozzles, i.e., chamber and venturi style nozzles; boom shields, hoods, electrostatics, air-assist booms, and pulse width modulation valves are also designed to reduce drift potential |
| Use a drift-control additive when needed | Drift-control additives increase the average droplet size produced by the nozzles; however, these additives should not become your only drift-reducing technique because they do not protect against otherwise poor spraying practices |



# UNDERSTANDING HERBICIDE MODES OF ACTION: INVALUABLE IN DIAGNOSING HERBICIDE INJURY AND PREVENTING RESISTANCE DEVELOPMENT

**Dean E. Riechers**

Herbicide mode of action may be defined as how a herbicide kills a plant. A working knowledge of herbicide mode of action can be beneficial when attempting to diagnose herbicide injury in the field. Ideally, a herbicide should provide good weed control without adverse effects on the crop. Many of the herbicides used today are not only very active on weeds at extremely low rates but also may injure the crop, especially under environmental conditions that lead to plant stress. Herbicide injury also can result from misapplication (sprayer overlap) or unintended applications, such as carryover, spray tank contamination, or off-target particle or vapor drift.

## MODE OF ACTION VS. TRANSLOCATION: WHEN VS. WHERE HERBICIDE INJURY SYMPTOMS DEVELOP

Herbicide mode of action and translocation are two important factors to keep in mind when diagnosing herbicide injury. Knowledge of herbicide mode of action can aid in determining how fast the injury symptoms will develop ("when" you see the injury), and knowledge of translocation patterns also can help to determine "where" the injury symptoms will first show up on the plant.

***Contact burners*** kill plants very quickly but only kill the plant foliage that comes in contact with the herbicide spray solution. Little if any translocation to the roots occurs. Examples of contact burners are paraquat (Gramoxone), Flexstar, Blazer, Cobra, Basagran, and Buctril. The injury symptoms associated with contact burner herbicides (rapid browning and eventual necrosis of treated plant tissues) develop so quickly that the herbicide cannot move out of the treated plant foliage to the roots, so these herbicides are not effective for controlling perennial weeds.

In contrast with the contact burners, amino acid biosynthesis inhibitors (glyphosate and the acetolactate synthase [ALS] inhibitors), fatty acid biosynthesis inhibitors (POST-grass herbicides such as Assure II, Select, or Poast Plus), and plant growth regulators (PGRs, including 2,4-D, Stinger, and Clarity) are considered systemic herbicides. Systemic herbicides are extremely slow acting and translocate throughout the entire plant, including moving down to the root system. Systemic herbicides are thus excellent management tools for controlling perennial weeds. Injury symptoms from the amino acid and fatty acid inhibitors typically include yellowing (chlorosis) and eventual necrosis that develops first on new leaves and meristems, but eventually the entire plant dies, usually within 2 to 3 wk. PGR symptoms on sensitive broadleaf weeds, or off-target injury to soybean, include stem twisting (epinasty) and leaf cupping or puckering.

Soil-applied triazines (Aatrex and Sencor) are also systemic herbicides that move throughout the plant, but translocation is limited to the transpiration stream (xylem), so only older, mature leaves and leaf margins that are transpiring the most receive the triazine herbicide. Typical triazine injury symptoms include chlorosis and eventual necrosis of the older leaves, especially around the leaf margins. Foliar-

applied atrazine shows injury symptoms that look more like that of the contact burners, and little translocation out of the foliage occurs.

Under certain environmental conditions, applications of the pigment inhibitor herbicides such as Balance or Callisto in corn, or carryover injury from Command can lead to corn seedlings that look white, or bleached. This injury can be confused with spray drift injury from glyphosate (Roundup or Touchdown) postemergence applications. Because glyphosate is a systemic herbicide, small amounts of spray drift onto corn leaves can kill the entire plant.

## ROTATING HERBICIDE MODES OF ACTION TO PREVENT WEED RESISTANCE

A large number of resistant weed biotypes have developed in Illinois during the past 10 yr, and they are mainly resistant to the ALS family of herbicides or the triazines. Some weed biotypes are even resistant to both of these classes of herbicides and are termed multiple resistant. Overuse of a particular herbicide, or similar herbicides that target the same site of action, can lead to a great deal of selection pressure on a herbicide target site (such as the ALS enzyme) and may lead to the development of resistance in normally sensitive weed populations. To prevent weed resistance, herbicides with different modes and sites of action need to be incorporated into an integrated weed management program. Our recent history with the ALS inhibitors in Illinois has demonstrated that reliance on one particular herbicide or herbicide family can lead to the rapid development of weed resistance.

Proceedings

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**Serving Agriculture and the Environment**

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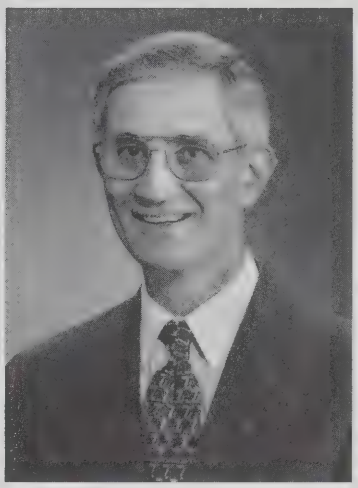
*The program planning committee and participants of the*

**2004 Illinois Crop Protection Technology Conference**

*wish to recognize and commemorate the exemplary careers of*

**Mr. Lloyd Burling**



**Dr. Gary Heichel**

Mr. Lloyd Burling will retire on February 1, 2004 after 35 years of dedicated service as President of the Illinois Fertilizer and Chemical Association. Lloyd has been an active conference participant for many years, and has contributed both time and resources toward the conference's development. For many years, Lloyd's suggestions have been instrumental in shaping this conference's planning committee, and he has continually urged IFCA members to attend. His tireless commitment to serving the needs of the fertilizer and agrichemical industry of Illinois will be a lasting legacy.

Dr. Gary Heichel will retire from the University of Illinois in May, 2004 after serving the needs of the agriculture industry for 35 years. Since 1990, he has provided vision and outstanding leadership as Head of the Departments of Agronomy and Crop Sciences. Dr. Heichel has long been a strong proponent for faculty and staff in Crop Sciences to participate in this conference, and has himself been a program speaker. Dr. Heichel has long supported a balance between applied and basic research and the critical need for research information to be passed along to our professional agricultural clientele. His skillful leadership and indelible dedication to the missions of the University of Illinois will be appreciated for many years to come.

We honor and pay tribute to both men for their outstanding dedication and contributions to the Crop Protection Technology Conference and crop production in Illinois.

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19 **Resistance to Pathogens in Soybean Cultivars—with Emphasis on Phytophthora Rot and Soybean Cyst Nematode**
*Dean Malvick and Terry Niblack*

22 **Practical Applications of Remote Sensing for Production Agriculture**
*Ken Copenhaver*

29 **GPS Navigation—The Good, The Better, The Unbelievable**
*Randal K. Taylor*

31 **Pulse Width Modulation to Control Spray Droplet Size for Increased Efficacy and Spray Drift Mitigation**
*Robert E. Wolf*

33 **Basics and Benefits of Drift Control Agents**
*Bryan Young*

36 **Herbicide Behavior in the Soil Environment**
*Bill Simmons*

38 **Corn Diseases and their Management**
*Gary P. Munkvold*

40 **Retail Seed Treatment 101**
*Mark Miller*

42 **Management of Forages for Better Yield and Profit**
*Rich Leep and Dean Malvick*

45 **Identification and Management of Winter Annual Weed Species**
*Mark M. Loux*

48 **Managing the Process of Seed Production for Product Purity**
*Barry Martin*

50 **Biotechnology Enforcement**
*Karen Heisler*

53 **Genetic Purity and Risk Management**
*Dennis Thompson*

55 **Fulfilling IP Contracts for Grains and Oilseeds**
*Lynn Clarkson*

56 **Soybean Aphid in the Midwest: Looking Toward a Dynamic Threshold—Emerging Recommendations, Lingering Questions**
*Eileen M. Cullen, John Gaska, Scott Myers, Bryan Jensen, Craig Grau, and Roger Borges*

61 **Weed Management Challenges from 2003**
*Aaron G. Hager*

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*Emerson D. Nafziger*

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69 **Cleaning Up Your Act: Reducing Pesticide Cross-Contamination**
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*Charles G. Rock*

73 **Repackaging Bulk Pesticides: What Does FIFRA Allow?**
*Dave Fredrickson*

75 **Agrichemical Facility Containment and On-Farm Storage Status Report**
*Warren D. Goetsch*

79 **Off-Label Applications and Pesticide Transportation Incidents**
*Gerald Kirbach*

81 **Product Update for Insect Management**
*Kelly Cook and Kevin Steffey*

86 **Product Update in Weed Management**
*Aaron G. Hager*

88 **Product Update in Disease Management**
*Wayne Pedersen*

90 **Corn and Soybean Nematodes: The Invisible Enemies**
*Terry Niblack*

91 **Field Crop Scouting Calendar and Techniques**
*Suzanne Bissonnette and Matt Montgomery*

92 **The White Grub Complex in Corn**
*Nathan Wentworth and Dave Feltes*

93 **Pandora's Pond**
*Dave Shiley*

94 **Corn Rootworm Management in the Corn/Soybean Cropping System**
*Kevin L. Steffey and Jared B. Schroeder*

# 2004 Illinois Crop Protection Technology Conference Planning Committee

## Co-Chairs:

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University of Illinois at Urbana-Champaign

**Dan Zinck**
Monsanto

# Program:
# January 7 & 8, 2004

## Wednesday Morning, January 7

| | |
|---|---|
| 9:00 AM | Welcome and Opening Remarks, Illini Rooms A, B, C, Aaron Hager |
| 9:10 AM | Remarks, Robert Easter, Dean, College of ACES |
| 9:20 AM | Welcoming Remarks, Charles A. Hartke, Director, IDOA |

**Keynote Session: Trends and Future** (1.0 CCA credit in Crop Management and 1.0 CCA credit in Pest Management) *Todd Gleason, Moderator*

| | |
|---|---|
| 9:30 AM | Trends and Future: Agriculture, Jean-Mari Peltier (invited) |
| 10:00 AM | Trends and Future: IPM, Ann Sorensen |
| 10:30 AM | Break |
| 10:45 AM | Trends and Future: Seed Industry, L. Sonny Beck |
| 11:15 AM | Trends and Future: Agrichemical Industry, Tom Hall |
| 11:45 AM – 1:00 PM | Lunch, on your own |

## Wednesday Afternoon, January 7

**Symposia A and B run concurrently with Seminars 1–5 from 1:00–2:30 PM**

**Symposium A: Pest Resistance**, Illini Room A (1.5 CCA credits in Pest Management) *Craig Abell and Lee Ward, Moderators*

| | |
|---|---|
| 1:00 PM | Insect Resistance in the Corn/Soybean Cropping System: Issues and Management, Kevin Steffey |
| 1:25 PM | The Trouble with Herbicide Resistant Weeds, Chris Boerboom |
| 1:50 PM | Resistance to Plant Pathogens in Soybeans: the SCN Story and More, Terry Niblack |
| 2:15 PM | Panel Discussion |

**Symposium B: Equipment and Application Technology** • Illini Room B (.5 CCA credit in Soil and Water Management and 1.0 CCA credit in Pest Management) • *Scott Bretthauer and Jean Trobec, Moderators*

| | |
|---|---|
| 1:00 PM | Practical Applications of Remote Sensing for Production Agriculture, Ken Copenhaver |
| 1:20 PM | GPS Navigation – The Good, The Better, The Unbelievable, Randal Taylor |
| 1:40 PM | Using Pulse Width Modulation (PWM) to Control Spray Droplet Size for Increased Efficacy and Spray Drift Mitigation, Robert Wolf |
| 2:00 PM | Basics and Benefits of Drift Control Agents, Bryan Young |
| 2:20 PM | Panel Discussion |

**Seminars 1–5 run concurrently with Symposia A and B from 1:00–2:30 PM**

**Seminar 1: Herbicide Persistence in the Soil Environment** • Illini Room C • *Bill Simmons*

Soil and foliar-applied herbicides are widely utilized for weed management in agronomic crops. A multitude of factors influence how herbicides behave in the soil environment. Learn how these factors influence herbicide persistence, availability, and dissipation. What factors increase the probability of herbicide carryover? What factors increase the availability of soil-applied herbicides? This session offers a comprehensive review of how current commercially available corn and soybean herbicides behave in the soil environment. (1.5 CCA credits in Soil and Water Management)

**Seminar 2: Corn Diseases and their Management** • Room 314B • *Gary Munkvold*

In this session we will discuss recent corn disease issues and their management, with an emphasis on stalk and ear rots. In particular, producing corn for human food use is an attractive market opportunity but it carries specific disease concerns, which also will be discussed. (1.5 CCA credits in Pest Management)

**Seminar 3: Retail Seed Treatment 101** • Room 404 • *Mark Miller and Derek Busboom*

Treating seeds at the retail level: Considerations before you get started and answers to questions you will ask afterwards. The purchase price of a seed treater is only the first step. Other seed handling equipment, personnel training and legal requirements will all need to be dealt with before you treat your first bag of seed. And what products will you use and how will recent registrations affect your decision-making process? (1.5 CCA credits in Pest Management)

**Seminar 4: Management of Forages for Better Yield and Profit** • Room 407 • *Rich Leep and Dean Malvick*

Forages can be a high-yielding and profitable part of a farming operation. Key components of forage production for optimum profitability will be presented. Topics to be covered include variety selection for high yields and value-added traits, good stand establishment, optimal nitrogen rates for grasses, weed and disease management, and tools to help in harvest timing. (1.5 CCA credits in Crop Management)

**Seminar 5: Identification and Management of Winter Annual Weed Species** • Room 314A • *Mark Loux*

Winter annual weed species have gained considerable attention over the past few years. This session will focus on the identification and biology of various winter annual weed species. Additionally, the practice of fall herbicide applications will be discussed. What are some of the factors that determine how well fall-applied herbicides work? Should growers always expect weed-free fields at planting time following a fall herbicide application? What are reasonable expectations for fall herbicide programs? (1.5 CCA credits in Pest Management)

| | |
|---|---|
| 2:30–3:00 PM | Break, South Lounge and Room 406 |

**Symposia A and B and Seminars 1–5 repeated concurrently from 3:00–4:30 PM**

**Symposium A (repeated): Pest Resistance** • Illini Room A

**Symposium B (repeated): Equipment and Application Technology** • Illini Room B

**Seminar 1 (repeated): Herbicide Persistence in the Soil Environment** • Illini Room C

**Seminar 2 (repeated): Corn Diseases and their Management** • Room 314B

**Seminar 3 (repeated): Retail Seed Treatment 101** • Room 404

**Seminar 4 (repeated): Management of Forages for Better Yield and Profit** • Room 407

**Seminar 5 (repeated): Identification and Management of Winter Annual Weed Species** • Room 314A

| | |
|---|---|
| 4:30–6:30 PM | IFCA-Sponsored Mixer – Illini Union Ballroom, 2nd floor |

This mixer is sponsored by the Illinois Fertilizer and Chemical Association. It is intended for everyone to meet with speakers, sponsors, and committee members in an informal atmosphere.

## Thursday Morning, January 8

**Symposia C and D run concurrently with Seminars 6–10 from 8:00–9:30 AM**

**Symposium C: Seed Purity Issues** • Illini Room A (1.5 CCA credits in Crop Management) • *Pete Fandel and Andy Knepp, Moderators*

| | |
|---|---|
| 8:00 AM | Managing the Process for Commercial Seed Production, Barry Martin |
| 8:20 AM | Biotechnology Enforcement, Karen Heisler |
| 8:40 AM | Genetic Purity and Risk Management, Dennis Thompson |
| 9:00 AM | Fulfilling Contracts, Lynn Clarkson |
| 9:20 AM | Panel Discussion |

**Symposium D: Emerging and Challenging Pest and Production Issues** • Illini Room B (1.0 CCA credit in Pest Management and .5 CCA credit in Crop Management) • *Chip Donahue and Kaleb Hellwig, Moderators*

| | |
|---|---|
| 8:00 AM | Soybean Aphid in the Midwest: Looking Toward a Dynamic Threshold–Emerging Recommendations, Lingering Questions, Eileen Cullen |
| 8:20 AM | Weed Management Challenges from 2003, Aaron Hager |
| 8:40 AM | Illinois Crop Disease Issues in 2003, Dean Malvick |
| 9:00 AM | Issues in Crop Management, Emerson Nafziger |
| 9:20 AM | Panel Discussion |

**Seminars 6–10 run concurrently with Symposia C and D from 8:00–9:30 AM**

**Seminar 6: Crucial Conversations, Tools for Talking when Stakes are High** • Illini Room C • *Ben Mueller and Anne Silvis*

*Crucial Conversations*, published in 2002, is the resource book for a training seminar that addresses the issue of how to have a discussion between two or more persons where stakes are high, opinions vary and emotions run strong. The workshop will provide an introduction to dialogue tools to help one successfully initiate difficult and important conversations with candor and achieve desired, positive outcomes. (1.5 CC A credits in Professional Development)

**Seminar 7: Got Dead Stuff?** • Room 314B • *Nancy Pataky, N. Dennis Bowman, and Jim Stedelin*

Find out about new plant and soil diagnostic techniques, technologies and resources that can help when things go wrong in the field. (1.5 CCA credits in Pest Management)

**Seminar 8: Cleaning Up Your Act—Reducing Pesticide Cross-Contamination** • Ballroom • *Dave Fredrickson and Michael Helms*

This presentation will discuss cross-contamination issues related to improperly or inadequately cleaning spray equipment, disposing of rinsates, and repackaging activities. Methods to reduce or eliminate cross-contamination will be introduced and various perspectives on disposing of pesticide wastewater will be discussed. (1.5 CCA credits in Soil and Water Management)

**Seminar 9: Water Quality Research in Illinois** • Room 314A • *George Czapar*

This session will provide an update on current water quality research in Illinois, including the new Strategic Research Initiative (SRI) funded by C-FAR. The session will also include a summary of water quality resources available on the internet. This information may be useful for local watershed groups or individuals developing nutrient management plans. (1.5 CCA credits in Soil and Water Management)

**Seminar 10: PDA Use and Data Management** • Room 407 • *Charles G. Rock*

Find out how to use affordable, leading-edge technology. The session will also include discussion of how to manage data more efficiently with today's tools. (1.5 CCA credits in Professional Development)

9:30–10:00 AM Break, South Lounge and Room 406

**Symposia C and D and Seminars 6–10 repeated concurrently from 10:00–11:30 AM**

**Symposium C (repeated): Seed Purity Issues** • Illini Room A

**Symposium D (repeated): Emerging and Challenging Pest and Production Issues** • Illini Room B

**Seminar 6 (repeated): Crucial Conversations, Tools for Talking when Stakes are High** • Illini Room C

**Seminar 7 (repeated): Got Dead Stuff?** • Room 314B

**Seminar 8 (repeated): Cleaning Up Your Act—Reducing Pesticide Cross-Contamination** • Ballroom

**Seminar 9 (repeated): Water Quality Research in Illinois** • Room 314A

**Seminar 10 (repeated): PDA Use and Data Management** • Room 407

11:30 AM – 1:00 PM Lunch, on your own

## Thursday Afternoon, January 8

**Symposia E and F run concurrently with Seminars 11–15 from 1:00–2:30 PM**

**Symposium E: Pesticide Repackaging, Storage, Transport, and Application Concerns** • Illini Room A (1.5 CCA credits in Soil and Water Management) • *Al Hansen and Larry Weller, Moderators*

| | |
|---|---|
| 1:00 PM | Repackaging Pesticides: What Does FIFRA Allow?, Dave Fredrickson |
| 1:25 PM | Agrichemical Facility Containment Update and On-Farm Storage Status Report, Warren D. Goetsch |
| 1:50 PM | Off-Label Applications and Pesticide Transportation Incidents, Gerald Kirbach |
| 2:15 PM | Panel Discussion |

**Symposium F: New Developments in Crop Protection Products** • Illini Room B (1.5 CCA credits in Pest Management) • *Dan Zinck and Dawn Nordby, Moderators*

| | |
|---|---|
| 1:00 PM | Product Update in Insect Management, Kelly Cook |
| 1:25 PM | Product Update in Weed Management, Aaron Hager |
| 1:50 PM | Product Update in Disease Management, Wayne Pedersen |
| 2:15 PM | Panel Discussion |

**Seminars 11–15 run concurrently with Symposia E and F from 1:00–2:30 PM**

**Seminar 11: Corn and Soybean Nematodes** • Room 407 • *Terry Niblack*

This session will discuss current and emerging nematode problems associated with corn and soybean production. (1.5 CCA credits in Pest Management)

**Seminar 12: Field Crop Scouting Calendar and Techniques** • Ballroom • *Suzanne Bissonnette and Matt Montgomery*

When do you scout for which pest? This session will discuss when and how you should be scouting for key insect, disease, and weeds of field crops at which growth stages during the growing season. Learn to use your time efficiently for the best economic return. (.75 CCA credit in Pest Management and .75 CCA credit in Crop Management)

**Seminar 13: The White Grub Complex in Corn** • Room 314A • *Nathan Wentworth and David Feltes*

In recent years, white grubs have become some of the most important secondary insect pests of corn. Japanese beetle grubs, Phyllophaga grubs, and grape colaspis can significantly reduce plant populations and corn yields. In addition, Japanese beetle adults may interfere with pollination by clipping silks. To control these insects, it is important to understand their biology and lifecycle, and it is imperative to scout fields and research the latest efficacy data. We will focus on these issues, and we also will discuss biology and control of the Japanese beetle adult. (1.5 CCA credits in Pest Management)

**Seminar 14: Pandora's Pond** • Room 314B • *Dave Shiley*

Ponds are simultaneously artificial and natural systems, which by nature make them difficult to manage. Management issues to be presented include impacts from run-off, drift, and aquatic vegetation control, as well as fish kill causes and basic fisheries management. (1.5 CCA credits in Soil and Water Management)

**Seminar 15: Corn Rootworm Management in the Corn/Soybean Cropping System** • Illini Room C • *Kevin Steffey and Jared Schroeder*

Corn rootworms have been present in Illinois for decades, and management of this pest complex continues to be a primary focus for corn producers every year. Now, more than ever before, corn producers can select from a significant diversity of rootworm-control products, including soil insecticides, insecticidal seed treatments, and transgenic hybrids. Issues that complicate rootworm management plans include the occurrence of rootworms in corn planted after soybeans, environmental effects on rootworm-control products, and insect resistance management plans for transgenic corn. All of these issues will be discussed during this session, with results from recently conducted research and survey efforts to support the discussion. (1.5 CCA credits in Pest Management)

2:30–3:00 PM Break, South Lounge and Room 406

**Symposia E and F and Seminars 11–15 repeated concurrently from 3:00–4:30 PM**

**Symposium E (repeated): Pesticide Repackaging, Storage, Transport, and Application Concerns** • Illini Room A

**Symposium F (repeated): New Developments in Crop Protection Products** • Illini Room B

**Seminar 11 (repeated): Corn and Soybean Nematodes** • Room 407

**Seminar 12 (repeated): Field Crop Scouting Calendar and Techniques** • Ballroom

**Seminar 13 (repeated): The White Grub Complex in Corn** • Room 314A

**Seminar 14 (repeated): Pandora's Pond** • Room 314B

**Seminar 15 (repeated): Corn Rootworm Management in the Corn/Soybean Cropping System** • Illini Room C

4:30 PM Adjourn

# Program Participants

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# Trends and Future: Agriculture

*Jean-Mari Peltier*

# Trends and Future: IPM

*Thomas Greitens and Ann Sorensen*

Environmental, economic, and policy challenges currently confront the integrated pest management (IPM) community. Challenges include insect adaptation to traditional IPM techniques, agriculture's impacts on water quality, the implications of emerging technologies such as genetically modified (GM) plants, the economic risk of implementing certain IPM practices, and the changing policy arena in which IPM operates. For commodity growers in Illinois, many of these challenges are magnified. Growers may not be able to implement practices that are healthier for the environment while concurrently trying to survive decreased prices for commodity crops such as corn and soybean. In such a situation, growers may choose to rely on agricultural techniques that increase yield instead of implementing environmental practices that could hypothetically decrease yield. To help solve these challenges, IPM professionals must further integrate research gleaned from a variety of disciplines into a comprehensive system of practices that stresses ecosystem health, public health, and economic efficiency. Such an integrated system, coupled with precision agriculture methods, may more readily respond to current and future environmental, economic, and policy challenges.

## Environmental Challenges

In Illinois, the IPM community faces two significant environmental challenges. The first challenge is the adaptation of the corn rootworm species complex to the corn–soybean crop rotation. Growers implementing this IPM tactic controlled the corn rootworm successfully for a number of years. However, over the past 15 years, the two-crop rotation has been losing its effectiveness. The second major challenge for Illinois growers is reducing the use of fertilizer. Research increasingly demonstrates that excessive midwestern fertilizer applications result in negative environmental effects. Intersecting both environmental challenges is the prospect of how the use of biotechnology could either help to solve these problems or simply contribute to other environmental problems.

Perhaps the most significant change for Illinois commodity growers is that the traditional IPM practice for controlling the northern corn rootworm, *Diabrotica barberi*, and the western corn rootworm, *Diabrotica virgifera virgifera*, is not as effective as it has been in the past. This corn rootworm species complex has adapted to the corn–soybean rotation. Traditionally, the corn–soybean rotation allowed growers to manage the corn rootworm with minimal insecticide applications. However, during the late 1980s, growers in east central Illinois began experiencing increased injury levels to corn from the corn rootworm (Levine and Oloumi-Sadeghi, 1996). Researchers believe that the widespread adoption of the corn–soybean rotation method allowed a variant of the western corn rootworm to emerge (Sammons et al., 1997). The new variant laid eggs in soybean fields, allowing for larvae to emerge the following year in corn crops. This allowed the larvae to feed on corn and caused extensive root injury and yield

reduction to corn not treated with soil insecticides (O'Neal et al., 2002). Perhaps most troubling, this new variant should spread to additional areas. Current models project the spread of this variant throughout Illinois to the eastern edge of Iowa within the next 10 years (Onstad et al., 1999).

To compensate for this adaptation, growers could try to use more insecticides. Populations of adult corn rootworms can be significantly reduced with aerial applications of insecticides (Meinke et al., 1998). However, this type of strategy will not permanently solve the problem. Research has shown that the western corn rootworm has developed resistance to insecticides such as methyl parathion and carbaryl in areas of Nebraska (Meinke et al., 1998). In addition, the public is increasingly concerned about pesticide use. Atrazine, used on corn to control broadleaf and grass weeds, has been discovered in groundwater sources near corn farming areas (Uri 1999).

As a result, the future of corn rootworm management will have to rely on strategies integrating several tactics compatible with the corn–soybean production system (Cuperus et al., 2000). Some of these tactics could include integrating precision agriculture methods with areawide approaches to control the corn rootworm. Precision agriculture methods allow the grower to use fewer pesticides and fertilizers by allowing a comprehensive analysis of field-specific information such as soil variability information and crop variability information (Elstein 2003). With this type of information, growers and IPM professionals could more easily identify this variant of the corn rootworm and target application schemes accordingly. An additional complicating factor is the release of transgenic hybrids for corn rootworm control and how and whether such varieties fall within the framework of IPM programs (Gray 2000). Because of the probability of resistance developing over time, Gray (2000) argues persuasively that the scientific and regulatory community should consider a prescriptive approach for the use of transgenic cultivars for corn rootworm control.

The controversy swirling around GM crops will continue for the foreseeable future. In the largest scientific experiment of its type on GM crops undertaken anywhere in the world, analysis from 3 years of field-scale trials showed that two of three GM crops, glufosinate ammonium-tolerant oil seed rape and glyphosate-tolerant sugar beet, seem more harmful to the environment than conventional crops (Brown, 2003). In these plants, spraying with herbicides reduced the numbers of weed species and various types of spiders, ground beetles, butterflies, moths, and bees in the fields of the GM crops. However, the third crop, GM atrazine-tolerant corn, allowed more weeds and insects to survive and may be recommended for approval. Even with approval, the political fallout in the European community and even the World Trade Organization is potentially enormous. As a result, politics and health concerns could serve as legal justifications to refuse the use of GM crops.

The European focus on maintaining biodiversity is just beginning to enter the political lexicon in the United States, largely through efforts by private foundations. As federal agencies expand their goals to include the preservation of biodiversity, commodity crops that are grown in vast acreages such as corn will come under increasing scrutiny. Although wildlife habitat is rarely addressed in IPM programs, key elements such as soil quality and beneficial insects both play an important role in minimizing the need for additional inputs. Reducing inputs, in turn, protects wildlife habitat such as streams and surrounding vegetation. For the IPM community, this corresponds to solving environmental challenges while maximizing the preservation of biodiversity. As a result, the IPM community may have to contemplate decreased uses of GM crops.

Another environmental challenge facing growers is how to reduce the use of fertilizer. This issue of IPM should be addressed because healthy plants, optimally fertilized, can withstand greater damage by pests. Excessive nutrient management applications have resulted in some environmental problems. For example, hypoxic and anoxic conditions in the Gulf of Mexico can be directly traced back to excessive nitrogen fertilizer applications in the Midwest running off into the Mississippi River (Burkart and James, 1999). Traditionally, IPM programs have been more focused on controlling pests than on improving plant health. However, by promoting use of technologies and better integrating and delivering information to growers, IPM programs can help growers improve plant health while reducing fertilizer use.

For instance, technology currently exists that allows growers to correlate nitrogen applications to site-specific soil characteristics, current nitrogen levels in the soil, and expected yield levels (Doerge, 2002). This knowledge allows the grower to avoid using blanket nitrogen applications for the entire area and instead focus nitrogen applications to needed sections of the field. However, the practicality of using such a system is somewhat in question. Doerge (2002) notes that while the technology exists to implement such a system, the high financial costs of soil sampling and uncertain environmental benefits preclude its widespread adoption. In contrast, other researchers present a more optimistic view of using variable nitrogen application techniques. Khosla et al. (2002) describe how dividing fields into management zones based on yield history, soil color from aerial photography, and previous growers' experiences often

can result in an increase in the agronomic use efficiency of the nitrogen applications. Such developments should increase the economic efficiency of the operation because growers target fertilizer applications to needed areas. In contrast, traditional fertilizer application schemes typically emphasize uniform rates no matter the condition of the soil.

Excessive nitrogen applications often result in poor water quality (Schepers et al., 1991). The use of advanced technology and precision agriculture should result in fewer impacts to water quality from fertilizer applications. These techniques, although technologically advanced, are relatively inexpensive to operate given the current state of global positioning system (GPS) and geographical information system (GIS) technology (Khosla et al., 2002). With such technology in place, the environmental effects of nutrient management may become negated. As concerns over water quality continue to increase among citizens and governmental officials, growers and IPM professionals will have to increasingly consider these methods to reduce the negative environmental effects of nutrient applications. Incorporating advanced technology as well as modeling techniques to examine how nutrient management applications affect the groundwater and surrounding surface water of the farming area benefits the grower and the public. Once implemented for nutrient management, this system also could be used to concomitantly minimize negative environmental effects and maximize the economic efficient use of pesticide applications and other agricultural practices.

## Economic Challenges

Using IPM tactics on commodity crops in Illinois, particularly corn and soybean, seems an ideal notion. After all, with IPM tactics, growers should realize environmental benefits without experiencing an economic disadvantage. However, the reality is much different. As profits for corn and soybean production continue to decline, growers will be increasingly reluctant to implement alternative agriculture practices without some type of financial incentive or some type of insurance to protect against potential economic risk.

These types of incentives have been given to growers before, although not specifically for IPM practices. For example, the Federal Agriculture Improvement and Reform Act of 1996 produced the Environmental Quality Incentives Program (EQIP). Even though research reveals that best management practices (BMPs) often generate savings with more efficient applications of pesticides and nutrients, growers do not readily adopt such practices (Mitchell and Hennessy, 2003). As a result, policymakers passed EQIP to provide growers with financial incentives to follow certain best management practices.

Where cost is the primary impediment to implementation, these types of subsidy-based programs are appropriate (Wu and Babcock, 1996). However, for practices such as IPM, issues such as profit uncertainty and risk aversion can influence adoption decisions as much as initial cost concerns (Mitchell and Hennessy, 2003). EQIP ignores the issue of how risk aversion influences adoption. However, types of green insurance have recently emerged that do address risk of adoption. Green insurance exists as a "single peril insurance" covering losses due to crop failures resulting from certain BMPs (Mitchell and Hennessy, 2003). As a result, with this type of insurance scheme in place, growers may be more willing to implement certain IPM or BMPs.

In the late 1990s, the Agricultural Conservation Innovation Center (ACIC) developed various risk insurance instruments focused on supporting reduced tillage methods, conservation tillage practices, and efficient nitrogen applications (Pesticide Environmental Stewardship Program, 1999). This led to work with IGF Insurance to create a policy for IPM tactics to control the corn rootworm. In this system, like other types of green insurance, if a certified crop consultant's recommendation to not treat the problem with insecticides fails, then the indemnity coverage commences with rates based on the observed root rating of the corn and lodging (Mitchell and Hennessy, 2003). After this work, ACIC developed a nutrient management policy that covers both nitrogen and phosphorus and presented it to USDA's Risk Management Agency (RMA). On December 12, 2001, USDA RMA approved the sale of ACIC's nutrient BMP risk management instrument in Minnesota, Wisconsin, and Pennsylvania for March 2003. ACIC and American Farmland Trust's research division are now working with Illinois to cut fertilizer applications by 20 million pounds on 143,600 acres of corn by 2005. With widespread use of targeted risk insurance or crop warranties by producers, ACIC-AFT researchers estimate growers could reduce fertilizer and pesticide runoff by 25% on 70 million acres of corn.[1]

It is worth noting that ACIC encountered difficulties in attempting to provide a type of risk insurance for IPM (Pesticide Environmental Stewardship Program, 1999). However, growers need risk insurance to implement IPM and other best management practices. The introduction of green insurance into the IPM community will not occur easily. With reduced funding levels and the uncertain political

[1] For additional information, see http://www.aftresearch.org

environment surrounding the expansion of federal programs such as EQIP to IPM practices, federal governmental assistance in this area is not likely. Therefore, developing a widespread IPM risk insurance will continue to be a difficult task, yet it must happen if IPM adoption is to increase among growers.

## Policy Challenges

Policy challenges also present a future concern for IPM programs. Due to the Governmental Performance and Results Act (GPRA) and a critical General Accounting Office report, the IPM community will have to develop performance goals, identify outcomes, and show that the implementation of IPM actually achieves those goals. IPM stakeholders and researchers discussed the need to formally assess IPM programs at the 1992 National Integrated Pest Management Forum as well as the Third National IPM Symposium (Sorensen, 1994; Lynch et al., 1997). Progress on assessment finally occurred after the General Accounting Office report *Management Improvements Needed to Further Promote Integrated Pest Management* (General Accounting Office, 2001). After that report, stakeholders and researchers generally agreed that IPM should be used to reduce the risk to human health from agricultural practices, reduce the environmental impact of agricultural practices, and reduce the economic barriers for growers adopting IPM practices (Coble, 2003). Consensus on these goals seems to be emerging within the IPM community. As a result, evaluators will analyze these goals when assessing IPM programs. In addition, growers and researchers within the IPM community will need to refer to these goals when designing specific IPM programs or advocating certain IPM techniques. To avoid future policy problems, the IPM community must develop an outcome-based mentality now that shows how IPM can reduce risk to human health and the environment while maintaining profitability.

For IPM programs to actually reduce environmental risk, growers will have to integrate various techniques and policymakers will have to coordinate governmental policy. Differing aims of programs often result in ineffective policy. For example, researchers have concluded that although the Conservation Reserve Program achieved its goal of reducing soil erosion on agricultural fields, the gains of the program were offset by increases in soil erosion due to crop subsidies (Goodwin and Smith, 2003). This research indicates that agricultural policy goals will have to be coordinated at some level for programs to reach performance targets. IPM researchers should note this need before designing any specific IPM program. To achieve the goals of IPM, the IPM community must first examine and then address how other federal programs impact a particular agricultural area. This task is daunting, particularly for a research community that typically avoids policy work.

The IPM community also faces the challenge of increasing technical assistance for growers to improve success rates on goals and outcome achievement in an uncertain financial climate. Technical assistance improves the implementation of new alternative production techniques by making the grower aware of the practice and helping the grower overcome technological or informational constraints (Uri, 1999). Technical assistance may help the IPM community and growers overcome many of the environmental and economic challenges discussed above. With the decline in assistance from agricultural extension offices, the private consulting community and agrichemical dealers could be invaluable asset in delivering IPM information to growers.

For example, growers are increasingly using *Bacillus thuringiensis* (Bt) corn. Yet, research indicates that a significant number of these growers violate the EPA-imposed 20% refuge requirement for Bt corn (Jaffe, 2003). The refuge requirement requires growers using Bt corn to grow Bt corn on 80% of their fields and non-Bt corn on 20% of their fields (Jaffe, 2003). The EPA implemented this requirement to delay insect resistance to Bt corn and to minimize potential adverse effects to other insects from Bt corn (Jaffe, 2003). However, research indicates that many growers were not aware of the refuge requirement but happened to comply with it as part of their normal agricultural practices (Jaffe, 2003). This unawareness shows that growers need more technical assistance in this area. Otherwise, environmental challenges will continually occur for growers. Insects will become more resistant to Bt corn, yields will decrease, and the grower will continually be confronted with new environmental and economic challenges.

## Conclusions

Although this analysis has surveyed some of the current and potential challenges facing growers who use IPM techniques in Illinois and offered some suggestions on how to meet these challenges, the current information on IPM is not all negative. Urban IPM and particularly school-based IPM programs continue to garner positive publicity for IPM techniques in the media and show the effectiveness of using IPM techniques to control certain pests to policymakers. For example, a Michigan school used IPM, rather than general chemical use, to successfully control a roach problem (Lavendel, 2001). In addition, researchers are using IPM techniques in experi-

mental trials to determine whether IPM techniques can result in the successful removal of environmental triggers that prompt asthmatic conditions in children (Kinney et al., 2002).

However, at the agricultural level, IPM still faces many challenges. To meet these challenges, IPM will have to continue to integrate different approaches of successful pest management. For the IPM community, this should result in viewing how IPM can benefit the whole ecosystem, not just a particular ecological or agricultural area. A narrow IPM focus just on particular problems or on particular areas has arguably led the IPM community to its current challenges of increased insect resistance, inorganic fertilizer pollution and perhaps even to the decreased economic situation experienced by many commodity growers in Illinois. Kogan (1998) viewed the IPM paradigm on ecological, socioeconomic, agricultural, and political scales. The future success of IPM may depend on integrating these four scales into a set of cohesive IPM practices in which all IPM stakeholders benefit. The use of advanced technology and other precision agriculture practices may result in such integration.

## References


Brown P. 2003. GM crops fail key trials amid environment fear. *The Guardian* (October 2, 2003). http://www.biotech-info.net/rootworm.html. Last accessed October 13, 2003.

Burkart M and James D. 1999. Agricultural nitrogen contributions to hypoxia in the Gulf of Mexico. *Journal of Environmental Quality* 28:850–859.

Coble H. 2003. IPM: Perceptions, pitfalls, and promises. Presented at the 4th National IPM Symposium, Indianapolis, IN. April 8, 2003.

Cuperus G, Mulder P, and Royer T. 2000. Implementation of ecologically-based IPM, in *Insect Pest Management: Techniques for Environmental Protection* (Rechcigl J and Rechcigl N eds) pp 171–204, Lewis Publishers, New York.

Doerge T. 2002. Variable-rate nitrogen management creates opportunities and challenges for corn producers. *Crop Management Online* (September). http://www.plantmanagementnetwork.org/cm/. Last accessed October 10, 2003.

Elstein D. 2003. Management zones help in precision agriculture. *Agricultural Research* 51:17.

General Accounting Office. 2001. *Agricultural Pesticides: Management Improvements Needed to Further Promote Integrated Pest Management.* Report No. GAO-01-815. General Accounting Office, Washington, DC.

Goodwin B and Smith V. 2003. An ex post evaluation of the conservation reserve, federal crop insurance, and other government programs: program participation and soil erosion. *Journal of Agricultural and Resource Economics* 28:201–216.

Gray M. 2000. Prescriptive use of transgenic hybrids for corn rootworms: an ominous cloud on the horizon, pp 97–103. http://www.biotech-info.net/rootworm.html. Last accessed October 13, 2003.

Jaffe G. 2003. Planting trouble: are farmers squandering Bt corn technology? Center for Science in the Public Interest, Washington,DC. http://www.cspinet.org/new/pdf/bt_corn_report.pdf. Last accessed October 10, 2003.

Khosla R, Fleming K, Delgado J, Shaver T, and Westfall D. 2002. Use of site-specific management zones to improve nitrogen management for precision agriculture. *Journal of Soil and Water Conservation* 57:513–517.

Kinney P, Northridge M, Chew G, Gronning E, Joseph E, Correa J, Prakash S, and Goldstein I. 2002. On the front lines: an environmental asthma intervention in New York City. *American Journal of Public Health* 92:24–26.

Kogan M. 1998. Integrated pest management: historical perspectives and contemporary developments. *Annual Review of Entomology* 43:243–270.

Lavendel B. 2001. Taking back the halls. *Audubon* 103:26-30.

Levine E and Oloumi-Sadeghi H. 1996. Western corn rootworm (Coleoptera: Chrysomelidae) larval injury to corn grown for seed production following soybeans grown for seed production. *Journal of Economic Entomology* 89:1010–1016.

Lynch S, Greene C, and Kramer-LeBlanc C. 1997. The third national IPM symposium workshop: broadening support for 21st century IPM, in *Proceedings of the Third National IPM Symposium/Workshop* (Lynch S, Greene C, and Kramer-LeBlanc C eds) pp 1–3. USDA-ERS Miscellaneous Publication No. 1542. USDA–ERS, Washington, DC. http://www.ers.usda.gov/publications/mp1542/. Last accessed October 10, 2003.

Meinke L, Siegfried B, Wright R, and Chandler L. 1998. Adult susceptibility of Nebraska western corn rootworm (Coleoptera: Chrysomelidae) populations to selected insecticides. *Journal of Economic Entomology* 91:594–600.

Mitchell P and Hennessy D. 2003. Factors determining best management practice adoption incentives and the impact of green insurance, in *Risk Management and the Environment: Agriculture in Perspective* (Babcock B, Fraser R, and Lekakis J eds) pp 52–66. Kluwer Academic Publishers, Boston.

O'Neal M, DiFonzo C, and Landis D. 2002. Western corn rootworm (Coleoptera: Chrysomelidae) feedings on corn and soybean leaves affected by corn phenology. *Environmental Entomology* 31:285–292.

Onstad D, Joselyn M, Isard S, Levine E, Spencer J, Bledsoe L, Edwards C, DiFonzo C, and Willson H. 1999. Modeling the spread of a western corn

rootworm (Coleoptera: Chrysomelidae) populations adapting to soybean-corn rotation. *Environmental Entomology* 28:188–194.

Pesticide Environmental Stewardship Program. 1999. Accelerating IPM adoption through risk management: final report. http://www.pesp.org/1999/acic99-final.htm. Last accessed October 10, 2003.

Sammons A, Edwards C, Bledsoe L, Boeve P, and Stuart J. 1997. Behavioral and feeding assays reveal a western corn rootworm (Coleoptera: Chrysomelidae) variant that is attracted to soybean. *Environmental Entomology* 26:1336-1342.

Schepers L, Moravek M, Alberts E, and Frank K. 1991. Maize production impacts on groundwater quality. *Journal of Environmental Quality* 20:12-16.

Sorenson A. 1994. *Proceedings of the National Integrated Pest Management Forum*. Center for Agriculture in the Environment, American Farmland Trust, Dekalb, IL.

Uri N. 1999. *Agriculture and the Environment.* Nova Science Publishers, Inc., Commack, NY.

Wu J and Babcock B. 1996. Contract design for the purchase of environmental goods from agriculture. *American Journal of Agricultural Economics* 78: 935–945.

# Trends and Future: Seed Industry

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# Trends and Future: Agrichemical Industry

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# Insect Resistance in the Corn/ Soybean Cropping System: Issues and Management

*Kevin L. Steffey*

Corn and soybean were grown on an estimated 151.4 million acres in the United States in 2002, representing approximately 47% of the field crop acres in the nation (NASS, 2002). Corn was grown on an estimated 61.9 million acres in 10 midwestern states (Illinois, Indiana, Iowa, Kansas, Minnesota, Missouri, Nebraska, Ohio, South Dakota, and Wisconsin), 79% of the estimated corn acres in the United States. In these same 10 states, soybean was grown on an estimated 56.45 million acres, 77% of the estimated soybean acres in the United States. Throughout these 10 midwestern states, corn and soybean are rotated annually for improved production of both crops and management of pests whose populations would increase if either crop were grown continuously. Consequently, the corn/soybean cropping system is the most prevalent type of cropping system among field crops grown in the United States.

The corn/soybean cropping system presents unique opportunities and challenges for management of insects and the potential for insect resistance, especially in the 21st century. The acres devoted to production of transgenic corn and soybean have increased significantly since their introduction (Council for Biotechnology Information 2003). The prospective plantings of transgenic soybean and corn in 2003 were estimated at 80 and 38% of all soybean and corn acres, respectively, in the United States. (NASS, 2003). The success of the current transgenic corn hybrids and soybean cultivars will encourage the development of newer and different transgenic hybrids and cultivars that will be major factors in pest management well into the future. The advent of transgenic crop technology also has had an impact on development of new chemical pesticides, reducing the number of active ingredients being developed by companies. As a consequence, the number of types of insecticides has declined to just a few that are being used or could be used on most of the planted corn and soybean acres. Finally, the development of conventional corn hybrids and soybean cultivars (i.e, with traditional plant breeding methods) resistant to specific insects will continue, with the concomitant concern about the target pest's ability to overcome the crop's resistance.

Issues regarding insect management and insect resistance in the corn/soybean cropping system are presented in this report. An overview of the insect resistance management issues is be presented, with references to specific current and potential challenges.

## Transgenic Crops for Insect Management

Since the mid-1990s, the most widely discussed and hotly debated issue associated with insect resistance in the corn/soybean cropping system has been the potential for target insects to become resistant to *Bacillus thuringiensis* (Bt) in transgenic Bt corn. To address this concern, the U.S. Environmental Protection Agency (EPA) requires companies that submit Bt plant-incorporated protectants for registration also to submit insect resistance management plans (U.S. EPA,

2002). Insect resistance management plans for Bt corn are intended to prevent or slow down the development of resistance to Bt within populations of target insects. Until 2003, all of the Bt corn products registered by EPA were transgenic hybrids developed for control of Lepidoptera pests, primarily the European corn borer and southwestern corn borer. Other lepidopteran pests controlled by some or all of these registered Bt corn products include armyworm, black cutworm, corn earworm, and fall armyworm. The two Bt corn products currently available for control of lepidopteran pests are YieldGard Corn Borer (Monsanto Company) and Herculex 1 Insect Protection (Dow AgroSciences LLC). Other transgenic events for control of lepidopteran pests currently are under development by several agricultural companies.

In February 2003, the EPA registered a Bt corn product for management of corn rootworms—western, northern, Mexican, and southern corn rootworms. YieldGard Rootworm corn hybrids were available on a limited scale in 2003. However, the efficacy of transgenic corn hybrids with rootworm protection has been excellent, and it is likely that YieldGard Rootworm corn hybrids will be planted on many acres in 2004. Other transgenic events for rootworm control currently are under development by several agricultural companies.

The insect resistance management plan for all Bt corn products (for management of either lepidopteran pests or rootworms) to date includes a requirement for a 20% structured refuge of non-Bt corn. In the near future, corn hybrids with traits for resistance against both lepidopteran pests and corn rootworms will be available. Monsanto Company has submitted information to the U.S. EPA in hopes of obtaining registration of YieldGard Plus, which includes insecticidal proteins for control of both lepidoptera pests and corn rootworm larvae. These "stacked" hybrids may be commercially available soon.

Because of important biological differences between corn rootworms (mating is much more localized, and there is less mixing of adults from different fields) and European corn borers, the resistance management plan for YieldGard Rootworm corn hybrids has some unique features and includes the following elements:

- Growers will be required to sign stewardship agreements if they purchase YieldGard Rootworm corn hybrids.
- Growers will be required to plant a structured refuge of at least 20% non-Cry3Bb1 (MON 863) Bt corn.
- The non-Bt corn refuge may be treated with insecticides to control corn rootworm larvae.
- Refuge acres should be planted as blocks **adjacent** to fields of YieldGard Rootworm corn or as **in-field strips** within fields of YieldGard Rootworm corn. (The non-Bt corn refuge for YieldGard Corn Borer and Herculex 1 hybrids must be planted within 0.5 mile of the Bt corn, although we at the University of Illinois recommend that the refuge be within or adjacent to Bt cornfields for control of European or southwestern corn borers.)
- Refuges planted as strips must be at least six rows wide, preferably 12 consecutive rows wide.

Unfortunately, while we have fixated on the potential for development of insect resistance to Bt in transgenic Bt crops, we have ignored some basic principles of integrated pest management (IPM). Applying chemical insecticides only when an insect population density has reached an economic threshold is one of the tenets of IPM. This simple tenet is both economically and ecologically sound. However, one of the refuge requirements for event MON 863 (the event from which YieldGard Rootworm corn was derived) is contrary to this tenet. From EPA's Notice of Pesticide Registration, EPA Reg. Number 524-528, February 24, 2003: "Growers will not be permitted to apply CRW [corn rootworm] labeled insecticides to the refuge for control of insect pests while adult corn rootworm are present unless the Cry3Bb1 field is treated in a similar manner." If the pest density in the YieldGard Rootworm field has not exceeded an economic threshold, the requirement suggests that concern about economics and the environment are subordinate to insect resistance management.

Regarding refuges, reports from the USDA have indicated that more than 20% of farms in 10 Midwestern states where Bt corn was planted failed to comply with federal planting requirements for insect resistance management, i.e., more than 20% of growers in Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Nebraska, Ohio, South Dakota, and Wisconsin who responded to the survey did not plant non-Bt refuges. Another 6% planted less than the required 20% refuge. This information is dismaying. Bt corn for management of European and southwestern corn borers has been available commercially since 1996. I refuse to believe that more than 20% of survey respondents were unfamiliar with the requirements and guidelines for planting Bt corn and a non-Bt corn refuge, which are widely and readily available. The National Corn Growers Association, state corn growers associations, seed companies and dealers, and university extension personnel all have produced and distributed copious educational and technical information. In addition, companies selling

Bt corn are required to notify buyers of the insect resistance management obligations.

I cannot overemphasize the importance of compliance to insect resistance management plans by growers who plant YieldGard Corn Borer hybrids and YieldGard Rootworm hybrids. Corn rootworms, in particular, have been able to adapt to many insect management tools or tactics (e.g., chlorinated hyrdrocarbon insecticides, methyl parathion [active ingredient of Penncap-M], carbaryl [active ingredient of Sevin], and annual crop rotation; read "Other Resistance Issues Specific to the Western Corn Rootworm" in this report). If insect resistance management plans for YieldGard Rootworm corn are ignored, corn rootworms might develop resistance to the Cry3Bb1 protein. In addition, failure to comply to insect resistance management plans associated with transgenic crops could result in cancellation of the products' registrations. Thus, the benefits of transgenic technology in agriculture would be short-lived.

## Insecticidal Seed Treatments

Another recent development in management of corn insect pests has been the increase in use of insecticidal seed treatments for control of subterranean insects, including corn rootworms, white grubs, and wireworms. All of the most recently registered insecticidal seed treatments—Gaucho and Prescribe (active ingredient imidacloprid), Cruiser (active ingredient thiamethoxam), and Poncho (active ingredient clothianidin)—have been in the nicotinoid chemical class, and all of these insecticides are systemic. Poncho will replace Gaucho and Prescribe in the marketplace, so Cruiser (Syngenta Crop Protection, Inc.) and Poncho (Gustafson LLC) will be the only insecticidal seed treatments applied to corn seeds before they are bagged and sold.

The current Bt corn products for rootworm control do not control other subterranean insects such as white grubs and wireworms, pests for which rescue treatments are not effective. Consequently, all Bt corn for rootworm control will be treated with one of the nicotinoid seed treatments. In addition, the required non-Bt corn refuge can be treated for control of corn rootworms, so it is possible that a large percentage of refuges will be planted with corn seeds treated with a nicotinoid insecticide. Despite this possibility, the EPA has not required a resistance management plan for registration of these nicotinoid seed treatments, or other chemical insecticides, for that matter. Furthermore, the companies that have manufactured the nicotinoid seed treatments are pursuing registration for their use on soybean seeds for control of bean leaf beetles and soybean aphids. It is entirely possible that a significant percentage of the corn and soybean acres in the 10 midwestern states indicated previously will be treated with nicotinoid insecticides in the near future.

## Pyrethroid Insecticides

Although insects that feed above ground in corn or soybean fields are not controlled with insecticides on as many acres as insects that feed below ground in corn, it is important to note that most of the foliar-applied insecticides currently registered for use in corn and soybean are pyrethroids. Due to their effectiveness and economics, pyrethroids are used preferentially when outbreaks of insect pests of corn and soybean occur. It is widely believed that the future for organophosphate and carbamates insecticides is limited, due primarily to the Food Quality Protection Act. Consequently, it is entirely possible that pyrethroids will comprise almost all foliar applications of insecticides in the near future. In addition, two pyrethroids—Capture (active ingredient bifenthrin [also the active ingredient in Empower]) and Force (active ingredient tefluthrin)—are registered for control of rootworm larvae. Many pyrethroids are labeled for control of rootworm adults, so it is likely that pyrethroids will be widely used to control both larvae and adults.

## Other Resistance Issues Specific to the Western Corn Rootworm

Two other issues regarding insect pest resistance in corn deserve mention, and both issues are associated with western corn rootworms. As a result of wide-scale spraying of insecticides for multiple years in succession to manage adult western corn rootworms in Nebraska, some populations have developed resistance to methyl-parathion and carbaryl (Meinke et al. 1998). In the eastern Corn Belt, a variant of western corn rootworm that lays eggs in crops other than soybean has developed, probably as a consequence of intense selection pressure imposed by rigid annual rotation of corn and soybean (Levine et al. 2002). The western corn rootworm has had a history of adapting to intense selection pressure (including development of resistance to chlorinated hydrocarbons throughout the Midwest, first reported in Nebraska; Ball and Weekman, 1962), so there is reason for concern regarding widespread exposure of this pest to a limited number of pest management tactics.

The variant of western corn rootworms that lays eggs in soybean fields also has generated renewed interest in applying insecticides to prevent the adults from laying eggs. This strategy is a reasonable

alternative to soil insecticides or any other rootworm management tactic in corn after corn because a threshold has been established, timing of the insecticide application is understood, and a scouting protocol exists. And if everything is done correctly, no soil insecticide is necessary to protect the corn roots the following year. Prevention of egg laying by rootworm adults is intended to be an alternative management practice, not a supplement to larval control.

So, can this strategy be used to manage corn rootworms in corn planted after soybean? Neither a threshold nor guidelines for timing an insecticide application to prevent western corn rootworms from laying eggs in soybean have been determined. Consequently, we do not recommend this practice to manage rootworms in corn planted after soybean; instead, we strongly discourage it. Nonetheless, some people are recommending the application of insecticides to prevent egg laying by western corn rootworms in soybean, but only if the grower agrees to use a soil insecticide or seed treatment when corn is planted the following year.

The practice of controlling western corn rootworm adults in soybean one year and then controlling the larvae in corn the following year is loaded with risk. This practice places a lot of selection pressure on the rootworm population, and the end result (the possibility for development of insecticide resistance) would leave many producers with few viable alternatives. Corn rootworms have adapted to every type of selection pressure we have placed on them (including crop rotation), and it is reasonable to believe that they will continue to adapt.

## "It's déjà vu all over again!" —Yogi Berra

The crop protection industry seems to be focused primarily on development of products that are prophylactic, rather than responsive to insect densities—Bt proteins for control of corn rootworms and European corn borers and insecticidal seed treatments for both corn and soybean are examples. The primary reason that the concept of IPM developed was the widespread and often prophylactic use of broad-spectrum insecticides, primarily the chlorinated hydrocarbons. Although Bt proteins are relatively narrow-spectrum insecticides, and although nicotinoid-based seed treatments are applied at very low rates, their use is liable to be widespread and indiscriminate. Consequently, many of the principles of IPM developed over the past four to five decades are at risk of becoming disregarded. Many acres of corn and soybean will be "treated" unnecessarily, placing considerable selection pressure on many species of insects. Although insect resistance management is important for a viable future in crop protection, insect resistance management strategies should be developed within a framework of IPM, the very foundation of sustainable crop protection programs.

## References


Ball H J and Weekman GT. 1962. Insecticide resistance in the adult western corn rootworm in Nebraska. *Journal of Economic Entomology* 55: 439–441.

Council for Biotechnology Information. 2003. U.S. farmers continue to embrace biotech crops, says survey, *Articles: Farmers*, April. http://www.whybiotech.com/index.asp?id=2825 (April 8, 2003).

Levine E, Spencer JL, Isard SA, Onstad DW, and Gray ME. 2002. Adaptation of the western corn rootworm to crop rotation: evolution of a new strain in response to a management practice. *American Entomologist* 48: 94–107.

Meinke LJ, Siegfried BD, Wright RJ, and Chandler LD. 1998. Adult susceptibility of Nebraska western corn rootworm (Coleoptera: Chrysomelidae) populations to selected insecticides. *Journal of Economic Entomology* 91: 594–600.

National Agricultural Statistics Service (NASS). 2002. Acreage, June 28. http://jan.mannlib.cornell.edu/reports/nassr/field/pcp-bba/acrg0602 (April 8, 2003).

National Agricultural Statistics Service (NASS). 2003. Prospective plantings, pp. 38–39, March 31, 2003. http://usda.mannlib.cornell.edu/reports/nassr/field/pcp-bbp/pspl0303.pdf (April 8, 2003).

U.S. Environmental Protection Agency (EPA). 2002. EPA's regulation of *Bacillus thuringiensis* (Bt) crops, May. http://www.epa.gov/pesticides/biopesticides/pips/regofbtcrops.htm (April 8, 2003).

# The Trouble with Herbicide-Resistant Weeds

*Chris Boerboom*

Herbicide-resistant weeds are troublesome to growers, ag professionals, and even weed scientists. Perhaps the biggest problem with resistant weeds is that we cannot predict when or where resistance will occur, which herbicide the weeds will become resistant to, or which weed species will be the next to become resistant. That may not seem like much of a problem, but if we, as weed scientists, cannot make reasonably accurate predictions, how can we convince growers and ag professionals to adopt management plans to delay resistance?

Even if a grower adopts all the "right" practices, we cannot guarantee that he or she will not have a resistance problem in the future. The grower may have a field that becomes infested with a resistant weed through no fault of his or her own. Resistant weeds may invade the field through sources such as windborne seed (e.g., herbicide-resistant horseweed seed may blow onto the field from a neighbor's field), resistant seed may be carried into the field with flood water, or other uncontrollable sources. Furthermore, even the right management practices are only thought to delay the length of time until resistance occurs. As long as a herbicide is being used, it is still providing selection pressure for resistance, and resistance will eventually occur. However, we predict resistance will be delayed for many years with the use of resistance management.

Despite these uncertainties, herbicide-resistant weeds are a problem that we (extension, dealers, consultants, seed sources, and growers) must address because herbicide-resistant weeds exist (15 different biotypes within Illinois) (Heap, 2003), and unless Charles Darwin was wrong, new resistant weeds will be selected in the future as long as herbicides are used. Even glyphosate, a herbicide that was predicted by some to be exempt from the resistance problem, has six documented cases of resistance in the world, and nine states report glyphosate-resistant horseweed (Heap, 2003). Although there are uncertainties about predicting when or where the next outbreak of resistance will occur, we should consider our current state of knowledge.

## Current Knowledge

We know that basic manufacturers are not investing heavily in the development of new active ingredients for corn or soybean, which is understandable given the saturation of market needs, adoption of transgenic crops, and devaluation of the herbicide industry. The discovery and registration of herbicides with new modes of action has declined greatly. In the past 20 years, the only new mode of action discovered and developed into products for corn and soybean was the *p*-hydroxphenal pyruvate dioxygenase (HPPD) inhibitors (Balance and Callisto). Glufosinate (Liberty) also was registered in the past 20 years, but its herbicidal action was reported in 1981. The potential for discovery and development of herbicides with new modes of action seems unlikely in the near future. Growers have experienced the benefits that accompany the development of new herbicides for decades. However, they must now be told that the

"pipeline" is dry and as resistant weeds evolve, existing herbicides will be the only option to control them. We must all be stewards of existing herbicides to maintain their benefits.

We know that multiple resistance can occur. Illinois has the notable distinction of having a waterhemp population with acetolactate synthase (ALS)-inhibitor resistance, triazine resistance, and protoporphyrinogen oxidase (PPO)-inhibitor resistance (Heap, 2003). This example has served as an excellent case study to heighten the awareness of the potential risks of resistance development and to illustrate our vulnerability by asking, "How would you control this weed if it is resistant to all of these herbicides?" Unfortunately, this question goes beyond academics. Multiple resistance has occurred and will continue to occur in the future.

We know that, generally, herbicide-resistant weeds have similar fitness to susceptible populations. Weeds that are equally fit produce the same number of seed. Thus, a resistant weed will not be outcompeted by its susceptible counterpart. This point is critical because it means that a resistance problem will not disappear if the herbicide is no longer used. The resistant weed seeds in the soil will germinate and grow into resistant plants, and plants that escape control, even from other herbicides, will produce more resistant seed for the seed bank. The only realistic way to eliminate resistance from a weed population is to eradicate the weed (which is not very realistic).

We also know many of the management consequences of resistance. In the year resistance is discovered, the grower may suffer significant yield loss because of poor weed control. In addition, the grower, dealership, or manufacturer may have to pay for expensive resprays. In future years, the grower and applicator lose the benefits and convenience of the original herbicide program. The consequences may be the need for more costly tank mixtures or sequential programs, or alternate herbicides that are more likely to cause crop injury. These "minor inconveniences" with resistance can accumulate and even reduce the rental or appraised value of farmland.

We are relying heavily on one major herbicide, glyphosate, in soybean production, and adoption of glyphosate-resistant corn is increasing. Some have questioned whether glyphosate resistance will occur beyond the current glyphosate-resistant horseweed in corn and soybean fields. However, approximately 70 million acres is being sprayed annually with glyphosate as the primary method of weed control (i.e., not just the burndown herbicide). With this major change in the use pattern of glyphosate, I predict additional cases of glyphosate resistance will be selected.

Management strategies that delay the selection for herbicide-resistant weeds also are known. Key strategies are to 1) use herbicides only when necessary to prevent economic loss; 2) rotate herbicide use among different modes of action, even if the crop has been rotated, and even if a herbicide-resistant crop is grown; 3) use tank mixtures that include different modes of action, but all modes of action must have activity against the target weed for this strategy to be effective; 4) rotate among crops with different life cycles; and 5) use mechanical control methods to complement herbicide treatments; and 6) scout fields regularly for weeds so as to respond quickly to suspected resistance.

Spraying weeds at the proper growth stage maintains a high effective dose. For glyphosate, there is concern that lower use rates or late applications to large weeds may reduce the effective dose and allow individual weeds to escape control. Hypothetically, these weeds could cross-pollinate and accumulate resistance genes over time and select for glyphosate resistance. This method is similar to the recurrent selection method used by some plant breeders. In addition, early applications minimize the risk of yield loss from early season weed competition.

## Conclusion

Throughout this article, I used the phase "we know" intentionally because I consider this information relatively common knowledge. The herbicide resistance problem is not a problem of ignorance. The knowledge of resistance exists. The resistance problem is actually a matter of action. Given the current situation and potential consequences, resistance management practices should be adopted. Are you prepared to take the next step?

## Reference

Heap I. 2003. The international survey of herbicide resistant weeds. http://www.weedscience.com.

# Resistance to Pathogens in Soybean Cultivars—with Emphasis on Phytophthora Rot and Soybean Cyst Nematode

*Dean Malvick and Terry Niblack*

Resistance issues occur with disease of field crops just as they do with insect pests and weeds. However, unlike resistance issues with insects and weeds where the focus is on development of insecticide or herbicide resistance, the major resistance issue facing crop disease management is "breakdown of resistance" in disease-resistant cultivars. This difference is due in part to the emphasis of management tactics for these three groups of "pests." That is, disease resistance is the major management tactic for disease control, whereas pesticide application is the major tactic for control of weeds and insects. The pest populations (pathogens, weeds, and insects) adapt to the selection pressure put on them by the main control tactic that they are exposed to. Based on observations and research, the major disease resistance problems seem to occur in soybean, with few to no major resistance problems documented in corn or wheat in Illinois.

Although breakdown of disease resistance is the main issue facing Illinois crop production, we also must be aware of potential development of resistance to fungicides in fungal pathogens. Fortunately, the news is good here—there is no known resistance to the major fungicides used for management of field crop diseases in Illinois. Seed treatment fungicides are a widely used fungicidal approach for disease control in Illinois field crops. Recently, a survey of sensitivity to metalaxl (Allegiance®)[1] and mefenoxam (Apron XL®)[2] in populations of *Phytophthora sojae* from Illinois soybean fields was conducted. Based on preliminary results, no resistance was detected to these widely used seed treatment fungicides. This information should not imply that we can ignore the potential problems of fungicide resistance that could arise. We must be particularly careful with the use of the strobilurin class of fungicides. Some of the commercial products that contain this class of fungicides are Quadris, Dynasty, Stratego, and Headline. The strobilurins all have a very specific site of action in the fungi they control, which suggests that fungal pathogens could develop resistance rapidly if proper fungicide resistance management protocols are not followed. We also must be on guard because resistance to strobilurins has been reported for several different fungal pathogens in other areas, so the risk is real and should not be disregarded. These products are rarely used on soybean. In corn, where they are frequently used, the usage patterns for these products fortunately tend toward infrequent spraying over a small part of the total corn acreage, which should dramatically reduce the development of stobilurin resistance. The same may not be true in wheat production systems. We must manage the use of strobilurins properly to minimize the risk of losing efficacy of this important class of fungicides.

Fungicide resistance is a potential problem for the future. The major resistance issues facing crop disease management in Illinois now, as noted above, is breakdown of disease resistance in disease-resistant cultivars. What we really mean is not that the resistance in the cultivars changes, but rather, the patho-

[1] Gustafson LLC, Plano, TX
[2] Syngenta Crop Protection, Inc., Greensboro, NC

gens adapt and change to overcome to same resistance that once was effective against them. The resistance remains the same, but the pathogens change. Two disease problems for which the issue of resistance is of particular importance in Illinois field crops are Phytophthora rot of soybean and soybean cyst nematode (SCN).

Phytophthora rot, caused by the soilborne pathogen *Phytophthora sojae*, is a common and significant disease of soybean in Illinois and throughout the Midwest. This fungus infects and kills soybean from seedling stages to maturity. Phytophthora rot is managed with cultivars with major (Rps) resistance, partial resistance, and seed treatment fungicides. Cultivars with major resistance genes have been the cornerstone for managing Phytophthora rot of soybean in Illinois. This disease, however, remains significant in part because all types of host resistance are not equally effective in Illinois. Breakdown of resistance to Phytophthora rot has been reported frequently in soybean cultivars with the three major Rps genes available commercially (Rps1a, 1c, and 1k). We (D. Malvick et al., University of Illinois) have determined that *Phytophthora* populations in many parts of Illinois now have the ability to kill soybean cultivars with the three most common Rps resistance genes. Similar breakdown of Phytophthora resistance has previously been reported for several other midwestern states. We collected *Phytophthora* from fields throughout Illinois and found races (pathotypes) in many areas that can kill soybean cultivars with the Rps1a, 1c, and 1k genes as well as several other Phytophtora resistance genes that are known (Figure 1). These results indicate a need for development of soybean cultivars with other major resistance genes and improved tolerance (partial resistance) to Phytophthora rot.

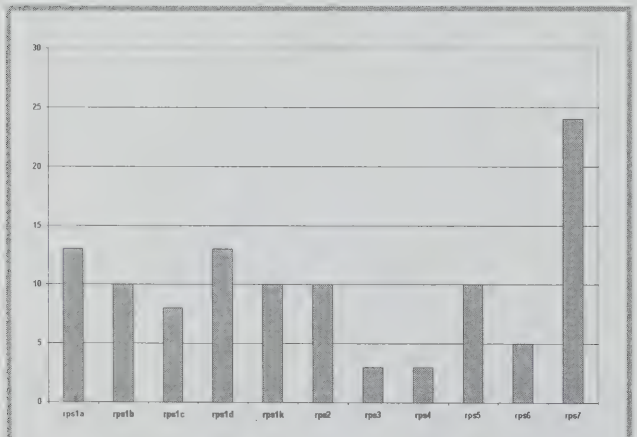



**FIGURE 1 Number of Illinois counties where P. sojae isolates that defeated specific soybean resistance genes were found (representing 24 counties from a survey conducted in 2001–2002 by Malvick et al., University of Illinois).**

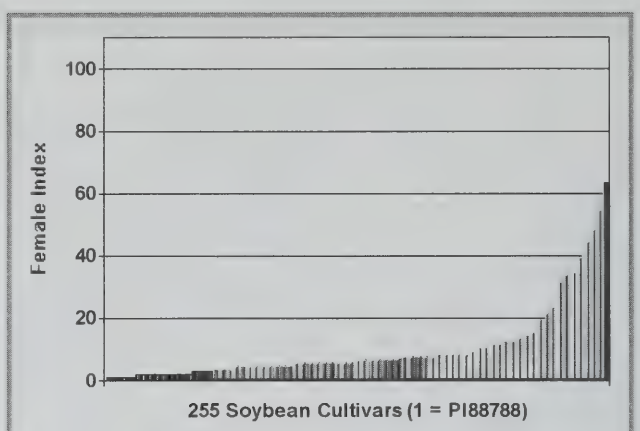



**FIGURE 2 Female Indices of "SCN-resistant" soybean cultivars screened with an HG Type 0 SCN population (Urbana3) in 2003.**

Soybean resistance to SCN differs in many ways from major-gene resistance to Phytophthora rot. One important difference is the distinction between qualitative and quantitative resistance when plants are challenged under controlled conditions. Major-gene resistance to Phytophthora rot is qualitative: if a soybean plant is susceptible to Phytophthora rot, then infection means death to the plant. Resistance means life. It's not equivocal. In contrast, SCN resistance is quantitative, meaning it is measured in increments: highly resistant, resistant, moderately resistant, and so on. Infected susceptible plants do not die—and they may not even look diseased—but they allow more SCN to develop than do infected resistant plants. Yes, SCN-resistant plants get infected, too, and at the same rates as susceptible plants. So what makes them "resistant"?

The SCN resistance of a cultivar is measured in two ways: by its yield in an SCN-infested field and by the number of nematodes it allows to fully develop on its roots. In both cases, resistance is measured as a comparison with a susceptible cultivar. Since 2001, we (T. Niblack, University of Illinois; G. Noel, USDA–ARS; and J. Bond, Southern Illinois University) have been screening all of the soybean cultivars labeled as SCN resistant and entered in the Soybean Variety Trials (http://vt.cropsci.uiuc.edu/) to five different SCN populations in the greenhouse (to see the data, use a search engine to find the Variety Information Program for Soybeans [VIPS soybean], because their site is undergoing renovation at this writing and the

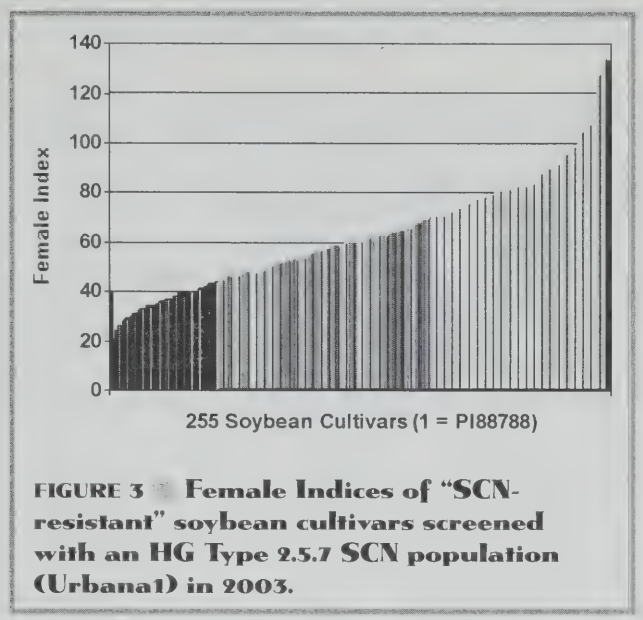



**FIGURE 3 Female Indices of "SCN-resistant" soybean cultivars screened with an HG Type 2.5.7 SCN population (Urbana1) in 2003.**

old address may not take you to the correct page). In this program, resistance is determined by the percentage of female SCN that develop on the roots of plants compared with a standard susceptible cultivar. This percentage is called the Female Index (Figures 2 and 3). If the Female Index is low (<10%), then the cultivar is highly resistant. If the Female Index is high (>60%), then the cultivar has no effective resistance. Cultivars with percentages in between are rated resistant (10–24%), moderately resistant (25–39%), and low resistance (40–60%).

The data (Figures 2 and 3) show you that 1) not all cultivars with the same source of resistance have the same level of resistance; and 2) levels of resistance depend on the type of SCN used for the test. Our data show that about 40% of the SCN populations in Illinois are virulent (i.e., will reproduce on) SCN-resistant cultivars that have the PI 88788 source of resistance and will behave more similarly to the one in Figure 3 than in Figure 2.

At least 500 soybean cultivars with resistance to SCN are available to Illinois soybean growers. Considering that >80% of the soybean fields in our state are infested with SCN, it would seem to be a good thing that so many cultivars are available. However, 90% or more of these cultivars were derived from the same source of resistance (resistant parent). As we emphasized for the Phytophthora rot example, the SCN story indicates a need for continued development of soybean cultivars with improved resistance, particularly through the use of different sources of resistance.

# Practical Applications of Remote Sensing for Production Agriculture

*Ken Copenhaver*

## Introduction

Since 1997, a joint program between National Aeronautics and Space Administration (NASA), the United States Department of Agriculture (USDA), and the commodity grower associations has been developing practical applications for remote sensing for production agriculture through joint research projects. This year, 2004, will represent the seventh and final year for Ag2020. During the project's 7 years, a number of applications have been scientifically tested through laboratory, plot-level, field-level, and finally large-scale demonstration. Many of the results have been promising. Although it has been discovered that certain applications do not necessarily work, such as prediction of nutrient levels in the soil or through the analysis of crop reflectance, other applications, such as detection of drainage tiles in bare soil and variable application of herbicide in soybean have shown positive results and are being implemented by commercial companies. This article briefly describes some of the more successful projects to come out of the Ag2020 initiative. More detailed information can be found for each of the projects at www.ag2020.org.

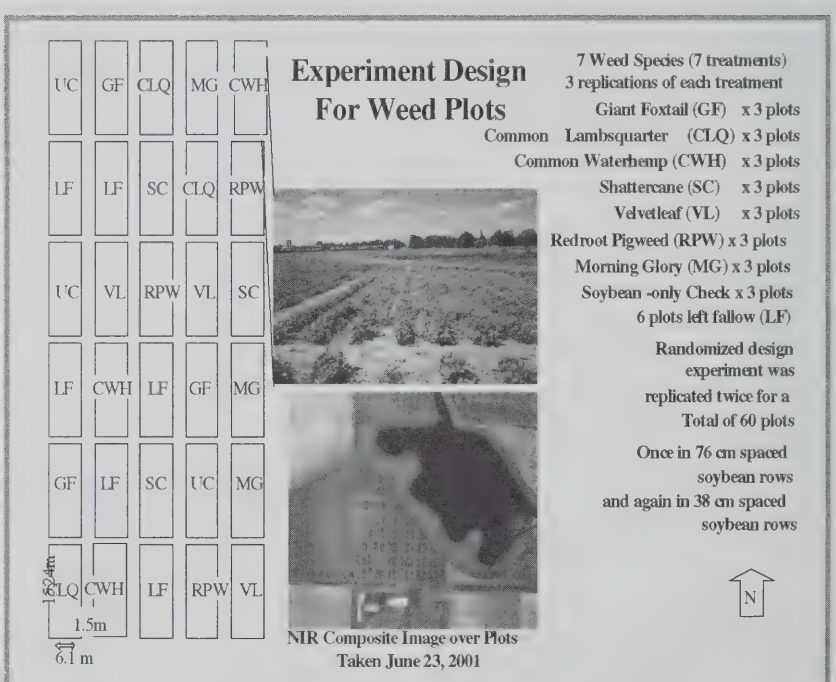

Experiment Design
For Weed Plots
7 Weed Species (7 treatments)
3 replications of each treatment
Giant Foxtail (GF) x 3 plots
Common Lambsquarter (CLQ) x 3 plots
Common Waterhemp (CWH) x 3 plots
Shattercane (SC) x 3 plots
Velvetleaf (VL) x 3 plots
Redroot Pigweed (RPW) x 3 plots
Morning Glory (MG) x 3 plots
Soybean -only Check x 3 plots
6 plots left fallow (LF)
Randomized design
experiment was
replicated twice for a
Total of 60 plots
Once in 76 cm spaced
soybean rows
and again in 38 cm spaced
soybean rows
N
UC GF CLQ MG CWH
LF LF SC CLQ RPW
UC VL RPW VL SC
LF CWH LF GF MG
GF LF SC UC MG
CLQ CWH LF RPW VL
1.5m
6.1 m
NIR Composite Image over Plots
Taken June 23, 2001

**FIGURE 1 Experiment design for weed delineation experiment at University of Illinois Crop Science Research Center in Champaign, IL.**

## Variable Rate Herbicide in Soybean

This project began with the development of weed-infested soybean plots in 2000 (Figure 1). For each of the 3 years of the plot-level experiment (2000–2002), weeds within soybean rows were easily separable from weed-free soybean rows by using a number of spectral and spatial resolutions (Copenhaver et al., 2002). The project also demonstrated that grass weed species could be separated spectrally from broadleaf weed species. Mixed results were found when efforts were made to spectrally separate specific weed species.

Positive results from the 2000 plot-level experiment led to the development of a field-level variable rate herbicide application project in 2001 (Copenhaver et al., 2001). Imagery was acquired in the spatial and spectral format of most currently available commercial imagery (Table 1). Weed infestations within the field were classified using the spectral information in the imagery into dense, moderate, and sparse infestations (Figure 2). This classification was then converted to a herbicide application map that applied 100% of the recommended amount of glyphosate to the dense weed patches, 67% to the moderate and 33% to the sparse. A comparison of treatments of herbicide variably applied to conventional 100% herbicide application treatments indicated that less herbicide could be used in areas imagery indicated weed pressures were less severe with no impact on weed control or yield.

The field level experiment was expanded to three fields in 2001 (Figure 3). Methodologies were similar. The only change was the resolution of the imagery was increased from 4 m with a 1-m panchromatic merge to 1-m multispectral imagery. The results were very similar to those from the 2000 experiment (Table 2). A classification of the imagery was successfully able to delineate the three levels of weed pressure. The reduced application of herbicide did not seem to affect weed kill effectiveness or yield for any of the three fields.

Also in 2001, a demonstration project was developed for 11 fields in Champaign County, Illinois. The same spatial and spectral resolution imagery was used for the project but instead of classifying the imagery into weed infestation zones a normalized difference vegetation index was threshold based on ground truth and analyst knowledge of the imagery into the three weed infestation levels. In addition, based on input from Syngenta, maker of Touchdown, the herbicide used in the project, rates were changed to 100, 75, and 50% based on weed infestation levels. These rates are on the label of Touchdown and are based on weed species and weed size. Also, weed control was not measured as intensively in the demonstration projects as the experiments. Weed kill effectiveness was determined with visual inspections by the grower, Syngenta, and Institute for Technology Development (ITD) personnel.

**TABLE 1 Spectral and spatial resolutions for airborne imagery acquired for variable rate herbicide project compared with commercially available satellite imagery.**

| Imagery Used for VRH Project in 2001 | Spatial Resolution | Green Band | Red Band | NIR Band | Pan Band |
|---|---|---|---|---|---|
| RDACS | 4 m | 520–600 nm | 630–690 nm | 760–900 nm | |
| RDACS | 1 m | | | | 400–900 nm |
| **Imagery Used in 2002 and 2003** | | | | | |
| Duncan | 1 m | 510–590 nm | 620–700 nm | 735–865 nm | NA |
| **Imagery from Commercial Satellites** | | | | | |
| IKONOS | 4 m | 520–600 nm | 630–690 nm | 760–900 nm | |
| IKONOS | 1 m | | | | 450–900 nm |
| Quickbird | 2.4 m | 520–600 nm | 630–690 nm | 760–890 nm | |
| Quickbird | 0.62 m | | | | 450-900 nm |
| Orbview III | 4 m | 520–600 nm | 625–695 nm | 760–900 nm | |
| OrbView III | 1 m | | | | 450–900 nm |

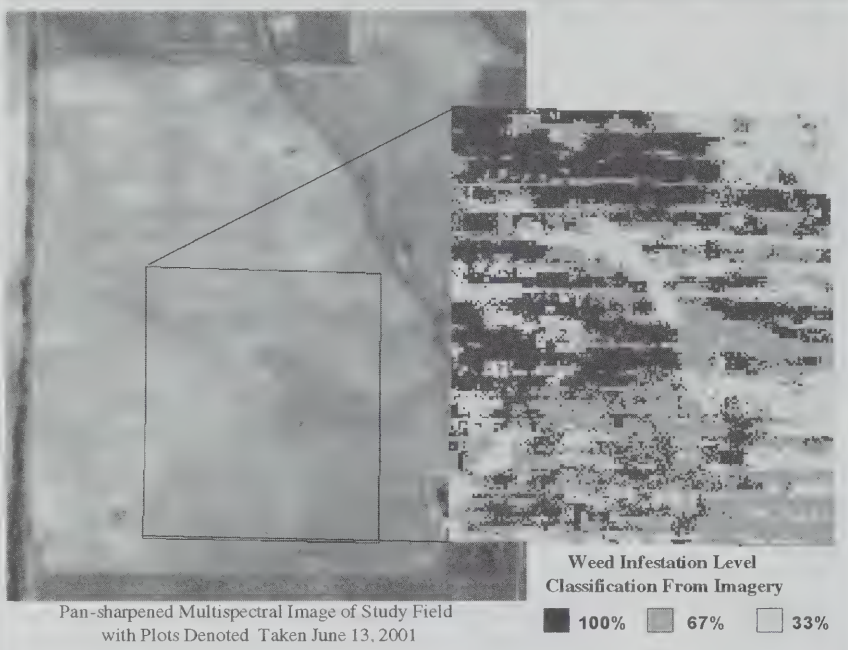



**FIGURE 2 Imagery and resulting classification for variable rate herbicide experiment.**

## Delineation of Drainage Tiles

A project attempting to delineate agricultural field tiles by using remote sensing began in 2001. The project was based on previous research indicating that remote sensing has the potential to quickly and accurately map the tiles (Verma and Cooke, 1996). This research indicated that bare soil images obtained at the proper time after a rainfall event could be used to delineate tile lines. The key to using the technology is proper timing. The rainfall event needs to be significant and the image acquisition should occur within 2–3 days after the rainfall event, but not while standing water is still in the field. Questions, however, still remained as to the proper spatial, spectral, and temporal resolutions needed to successfully apply the technology. Additionally, research was needed to develop an effective and cost-efficient image processing methodology for mapping the tile lines. The project developed for Ag2020 in 2001 addressed these issues (Varner et al., 2001).

The tile delineation project continued from 2001 to 2003. In each of the 3 years, the project attempted to address different areas of concern regarding tile drainage delineation. In 2001, the project looked to validate the existing research by delineating newly laid tile that had been geolocated by using a global positioning system (GPS). Tiles were identified in two manners: 1) linear areas of dry soil with higher spectral reflectance, and 2) darker, linear features with moist soils. The project indicated a good level of success when delineating tiles for conventional tilled fields (Figure 4). However, fields with soybean residue showed mixed results and it was difficult to delineate tiles beneath fields with corn residue.

For the project in 2002, efforts were made to delineate older tiles in fields at the Davis Purdue University Agricultural Research Facility near Muncie, Indiana (Figure 5) (Varner et al., 2002). Some of these tiles were previously mapped. Other tiles were not mapped and the location was unknown. When potential tiles were delineated in the imagery, Purdue staff used traditional field techniques to determine the image accuracy. The results were similar to 2001 but with lower accuracy for the older tiles.

Of the image processing techniques that were studied in the 2001 and 2002 projects, two proved to have the highest level of accuracy: a technically advanced method using a directional edge detect enhance-

**TABLE 2 Comparisons for weed kill and yield between plots with a conventional 100% herbicide application and plots with variable amounts of herbicide applied based on imagery.**

| Field | Test | Standard Rate | Variable Rate | P Value |
|---|---|---|---|---|
| Dalenberg 2001 | Weed kill | 99.1% | 98.6% | |
| | Yield | 58.12 bu/acre | 58.22 bu/acre | 0.73 |
| Ehler | Weed kill | 90.9% | 92% | 0.76 |
| | Yield | 59.54 bu/acre | 59.17 bu/acre | 0.85 |
| Wolf | Weed kill | 98.7% | 99.4% | 0.31 |
| | Yield | 57.53 bu/acre | 57.08 bu/acre | 0.68 |
| Dalenberg 2002 | Weed kill | 97.7% | 99.9% | 0.3 |
| | Yield | 50.41 bu/acre | 47.58 bu/acre | 0.13 |

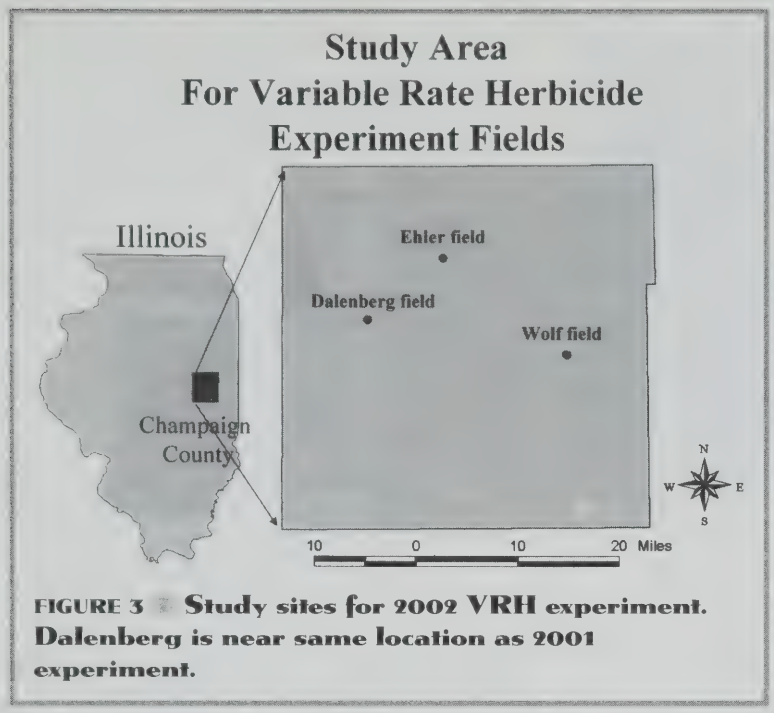



**FIGURE 3 — Study sites for 2002 VRH experiment. Dalenberg is near same location as 2001 experiment.**

ment PCA method (DEDEP) and a method applying an edge-enhanced filter followed by a simple linear data stretch.

In 2003, the positive findings from the previous 2 years were used to conduct a demonstration of the technology with cooperation from commercial partners. The demonstration was conducted in two parts with two different image providers. The first part focused on the development of a tile identification utility to add to Agri-Vision's (a commercial data provider located in Indiana) current image viewing software (www.agri-vision.net). The utility was based upon methods developed by ITD during the previous tile project work. Agri-Vision was contracted in 2003 to fly two counties in Indiana for the purposes of locating tiles.

The second part of the 2003 project focused on the development of a tile identification product by using previously collected panchromatic imagery over Iroquois County, Illinois. Precision Aviation, an aerial photography firm, acquired the imagery in spring 2001 and spring 2002. Precision Aviation has established a partnership with the Soil and Water Conservation District of Iroquois County to provide their local growers with tile information.

Costs for the imagery have been estimated to range from $0.77 per acre from a commercial satellite provider to $1.59 per acre for digital airborne imagery. The average price for imagery based on estimates from a number of sources was $1.32 per acre. A producer focus group indicated that these prices are within the range they would be willing to pay for the information the tile drainage maps provide.

## Use of Imagery to Assist in Scouting Seed Corn and Corn and Soybean Production Fields

An increasingly common use of remotely sensed imagery for agriculture is as a tool for the field scout. Imagery can be used to locate field anomalies and to gauge the general health and condition of a field or farm. An Ag2020 project from 2001 to 2003 looked at the economic feasibility of using imagery to assist scouts in the detection of problems in corn, soybean, and, in 2003, seed corn fields.

For the project, scouts were given a value-added product, such as a vegetation index map (Figure 6), that displayed reflectance anomalies within the field associated with plant health. These maps assisted the scout by delineating specific areas within the field that may warrant field scouting. Areas where plants are under stress may indicate insect or other pressures. Areas of increased plant vigor in early season imagery may contain weeds. By examining the imagery products, the scout is directed toward problems and can spend the same amount or even less time in the field while having more confidence

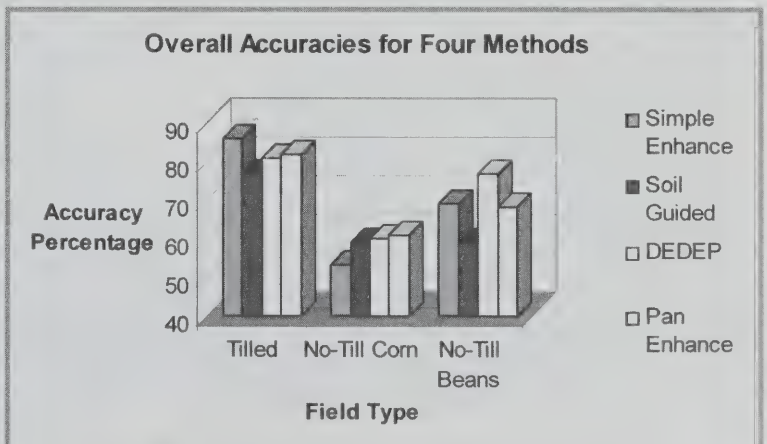



**FIGURE 4 — Comparison of accuracy results for delineation of tiles under different residues, tillage.**

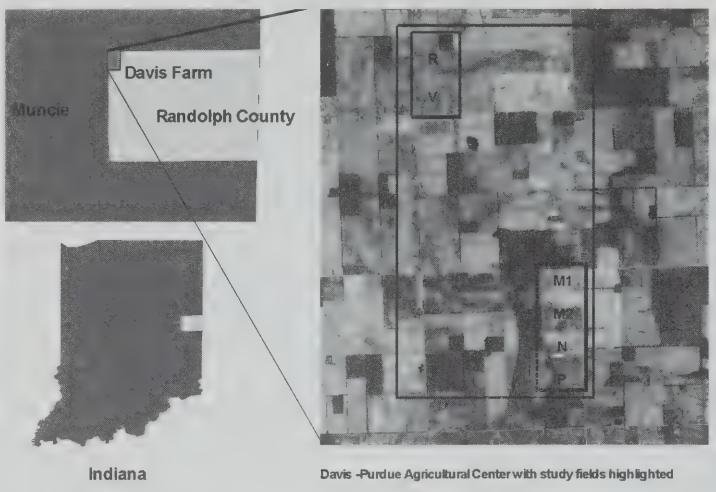



**FIGURE 5 Study area for 2002 tile delineation project.**

that trouble spots have been visited. The maps were displayed on an iPaq hand-held computer with a global positioning system in the field allowing the scout to see the stress level the map was indicating for his or her current location and to go to specific areas where the map indicated a problem might exist (Figure 7).

The projects in 2001 and 2002 demonstrated the usefulness of imagery in identifying problems in three production soybean–corn rotations in Central Illinois (Johnson et al., 2001, 2002). Problems in the fields identified by imagery included early and late season weed infestations, stress and damage caused by insects, disease, drought, and nitrogen deficiences. The imagery also identified exposed tiles and subsoil and, in several instances, damage caused by lightning, wind, and hail. However, based on economic focus groups attented by growers, it was felt that the added costs if imagery and hardware was not cost-effective for production corn and soybean.

For 2003, NASA approached a major seed corn company, Remington Seeds, whose manager had experience with imagery in the past and felt that it could be useful for scouting as well as be able to assist them in making management decisions. The 2003 project evolved into a large-scale demonstration project of the technology collecting imagery throughout the season for 54 seed corn fields in west central Indiana.

Imagery was acquired beginning in May and continued through the beginning of harvest. The schedule of image missions was determined by the seed company based on growth stage. The imagery was delivered in a form suitable for hand-held computers. The computers were equipped with GPS and mapping software. The scouts and managers were given training and used the imagery to guide them to locations to scout and examine. Scouting locations and areas of interest would be recorded by GPS and allow measurements and notes to be associated with the locations. Early season imagery was used to guide sampling for population measurements and to identify weed infestations. After the canopy began developing, vegetation index maps were generated from the imagery based on image statistics. The maps identified areas doing better and worse than the field as a whole.

Some findings from the 2003 project include better mapping of drainage problems and delineation of hot spots within the fields. Heavy rains in May 2003 lead to many drown-out areas in the field and caused replanting of some of the corn. The image maps guided replanting decisions and were used by Remington to show the grower this problem in the hopes of improving drainage. The imagery was used to identify these areas and map their extent (Figure 8). The imagery also successfully identified weed infestations not reported by the scouts (Figure 9). It was also discovered that there were more "hot spots" in the fields than were known by the managers (Figure 10). The area in Figure 10 marked "unknown" was identified by the imagery and not found by scouting the field. Based on this map, this area was later cut. Each of these situations has impact on the yield and quality of the seed and thus an economic

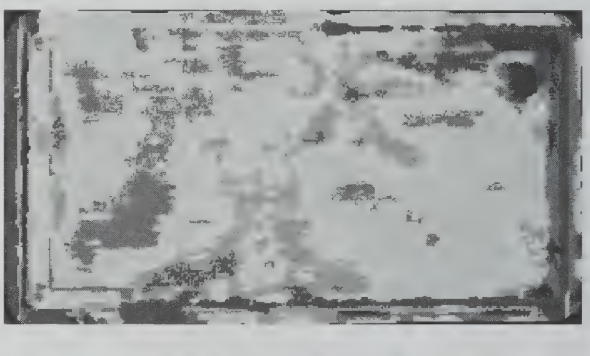
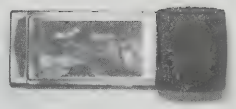



**FIGURE 6 Typical vegetation index map that would be given to grower.**

value. An economic analysis will be performed by the University of Illinois and will be used by the seed company to determine whether to use imagery.

## Estimating Corn Yield

Being able to accurately estimate yield before harvest is important in seed corn production and planning. Prior research has shown that airborne or satellite imagery can show the variability of the crop in the field. A project undertaken during the 2002 and 2003 growing seasons attempted to determine whether this variability might be useful in directing field personnel to locations from which to make yield estimates that are more accurate than traditional estimates.



- Compaq iPAQ Computer
- ESRI ArcPad GIS
- GPS
  - Differential correction using FAA WAAS
  - Accurate to within 2 to 5 meters

**FIGURE 7 Equipment used by scouts for crop scout project fieldwork.**

In 2002 the yield prediction project looked at eight seed corn fields in central Illinois (Gress et al., 2002). In 2003, the yield estimation project used the study area of the 2003 Ag20/20 Crop Scout project, with 54 fields comprising of over a dozen varieties from which to sample. The objective was to determine whether the image-based yield estimates are more accurate than the traditional random sampling.

For the 2002 project broad-band, 1-m resolution multispectral airborne imagery was collected on eight dates from June 8 to August 15. For the 2003 project, imagery was obtained over the fields on July 16 and August 25. The 2003 project acquired imagery in two red and one infrared wavelength at a ground resolution of 2 m. The wavelengths were specifically chosen as previous research has indicated they are sensitive to differences in the vegetation canopy and the health of the corn plants.

An isodata classification was then performed on the imagery to group areas in the image into statistically distinct categories. The 2002 project used multitemporal imagery for the classification. The 2003 project focused on imagery from the August 15 data collection. These unique categories represented the variability of the crop. In most of the fields, a split was made, i.e., where part of the field was planted with sterile female plants and the other part with fertile female plants. In those fields, each part was

**FIGURE 8 Dark areas indicating standing water in the imagery. Seed corn in these areas had to be replanted.**

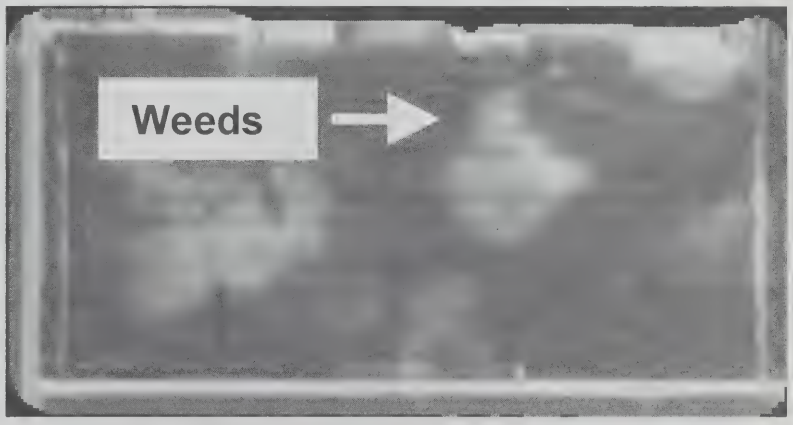



**FIGURE 9 Example of imagery for crop scout project with weeds clearly identified.**

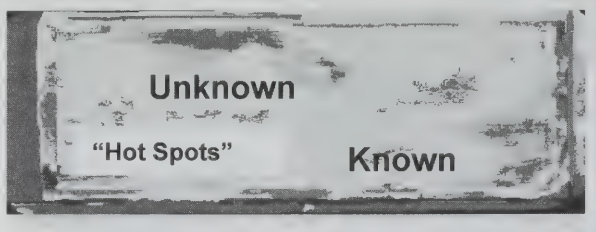



**FIGURE 10 Study area for 2003 seed corn scouting project.**

separated and processed separately. This approach was necessary because the yield and management practices are different.

Random points within each category were then generated for each field. The points were loaded onto a hand-held computer equipped with GPS and mapping software. Field personnel navigated to each point, counted the number of ears along a 17½ foot section of the corn row and sampled five ears. The number of rows and columns of kernels on each ear, along with the number of ears was recorded on the computer. Later the total number of kernels on each ear was calculated and an average was derived from the five sample ears. From the average number of kernels a yield in bushels per acre is derived for that location using the formula $yield_{bu/acre}$ = (no. kernels * no. ears)/90. A final field average based on all of the sample points and weighted by the area of the field occupied by each category was calculated. The same person would then go into three of the field corners and randomly select a sample location. The same procedure as described above would be followed, resulting in a field-level estimate based on the traditional method. After harvest, the two different estimates are compared with the actual estimate to determine whether there are any significant differences between the two approaches. If the image-directed approach is more accurate, the additional costs of this approach will be determined and the seed company will decide whether it is cost-effective for them.

## Conclusions

Some of the applications examined during the Ag2020 program seem to hold promise for the commercial market. The final year of the program will be spent developing relationships with commercial remote sensing data providers to transfer the technology to the commercial sector so products such as variable rate herbicide and tile drainage maps can be offered on a large scale to commercial producers. Final reports from all of the above-mentioned projects are available by contacting sources on the Ag20/20 Web page.

## References

Copenhaver KL, Gress T, White S, and Varner B. 2001. Weed detection and delineation in soybeans. Final Report Year 2 to NASA ESAD.

Copenhaver KL, Gress T, White S, and Varner B. 2001b. Variable rate application of herbicide using imagery to detect weeds at scattered acres farms, Illinois. Final Report to NASA ESAD 2001.

Gress T, White SE, and Johnson J. 2002. Using remotely sensed data as a tool for field sampling based corn yield estimation: a demonstration. Final Report Year 1 to NASA ESAD.

Johnson JW, Copenhaver KL, and White SE. 2001. Image-based crop scout. Final Report Year 1 to NASA ESAD.

Johnson JW, Copenhaver KL, and Gress T. 2002. Image-based crop scout. Final Report Year 2 to NASA ESAD.

Varner BL, Gress T, Copenhaver K, and White S. 2001. The effectiveness and economic feasibility of image-based agricultural tile maps. Final Report to NASA ESAD 2001.

Varner BL, Gress T, Copenhaver K, and White S. 2002. The effectiveness and economic feasibility of image-based agricultural tile maps. Final Report to NASA ESAD 2002.

Verma A and Cooke R. 1996. "Mapping subsurface drainage systems with color infrared aerial photographs." Urbana-Champaign: Department of Agricultural Engineering, University of Illinois.

# GPS Navigation—The Good, The Better, The Unbelievable

*Randal K. Taylor*

Navigation of agricultural vehicles through the use of global positioning system (GPS) is becoming more popular due to the increasing availability of GPS receivers and changes in farming practices. The availability of free differential correction over a wider area has increased the number of lower priced differential GPS (DGPS) receivers. Also, the increase in reduced and no-tillage acres has amplified the importance of crop protection application and created challenges for producers attempting to follow their desired path in the field. Crop stubble creates an environment where seeing the previous pass can be difficult, and traditional markers have had limited success. Several manufacturers have introduced GPS guidance systems to address these problems and several more will enter the market soon. Systems range from those that indicate a desired path to the operator via a display of lights or image to ones that automatically steer the vehicle. Automatic steering systems for tractors and self-propelled sprayers are available today and more manufacturers are starting to produce them. Furthermore, we are making progress toward autonomous or operatorless vehicles for agriculture.

## The Good—Operator Steered

The basic starting point for GPS navigation is some type of a light-bar or visual method of giving the operator steering advice. These items come in many designs with varying levels of accuracy, and flexibility or openness of the system, and other features.

Foremost, the system must provide sufficient pass-to-pass accuracy, or precision, to provide the driver with adequate feedback. However, extremely accurate GPS systems are not required because the operator is likely to make slight steering errors anyway. Also, the system must present the "steering advice" in a manner that the operator can interpret and make the appropriate steering correction. In general, most of the systems that are currently being sold can provide a GPS signal that is more precise than most operators' can drive. Several recent studies have attempted to evaluate dynamic accuracy of current GPS technology. Although there is some variability in the results, DGPS receivers commonly used for guidance have pass-to-pass errors less than 10 inches. Some receivers have pass-to-pass errors less than 6 inches.

Probably the most important item to consider with respect to accuracy is the operator interface. Everyone has personal preferences and the system that fits one person's needs may be unacceptable to someone else. Operator feedback provided with some sort of light array seems acceptable for most operators, but probably takes a little longer to learn. The "moving highway" type displays are probably easier to learn, but often drivers will spend too much time watching the display. Because personal preference plays such an important role in the operator interface of a guidance system, research into which system is better is not feasible.

System flexibility is an important aspect of all guidance systems. Although the initial purchase

decision may be based entirely upon guidance, future uses may be much more diverse. The GPS receiver from a guidance system could be used for other functions such as yield mapping or variable rate application. The ability to easily move the components from one application to another is beneficial.

Most GPS guidance systems offer at least two path modes: straight line and contour. The most common, and simplest, feature of most guidance systems is straight line guidance. The operator drives and logs a reference pass, and the parallel passes of a preset swath width are created. The operator logs the reference pass by recording an A point at the beginning of the pass and a B point at the end. Each time the operator turns, the guidance system finds a new pass and indicates a steering pattern to follow this pass. In the straight guidance mode, all subsequent passes are typically referenced to the initial A-B line. The reference pass is typically placed in a location that is easily driven in a straight line. This place could be along a fence line or road. Straight line guidance can be conducted in back and forth or racetrack patterns. Contour guidance is a feature of some systems. This feature allows the operator to drive a curved pass. At the end of the first pass, the guidance system creates a new pass parallel to the initial pass. Each subsequent pass is typically created parallel to the previous pass and not the initial pass.

## The Better—Automatically Steered

As we start to consider automatically steered vehicles, GPS accuracy becomes more important. We now must consider the benefits of precision (good pass-to-pass accuracy) and absolute accuracy. Absolute accuracy allows you to drive the same path at a later time with little deviation. To obtain high absolute accuracy and pass-to-pass precision, you will probably need a real-time-kinematic (RTK) GPS system. The RTK systems require a separate, user-owned base station to provide additional differential correction.

High-quality dual frequency receivers have been introduced that have the necessary precision for auto steering. However, they are typically not as accurate as RTK systems. The pass-to-pass precision is sufficient, but they may not be able to return to the same exact spot at some point in the future. With continued advances in GPS technology, we will see improved pass-to-pass precision and absolute accuracy without the need for a separate base station.

The multiple patterns and paths that are available for user steered GPS guidance systems are typically not available to automatically steered systems. The influence of vehicle roll has been a problem for auto steer systems when receivers are mounted on the top of cabs. The rapid lateral movement of the GPS receiver leads to erroneous information for the steering system. However, the inclusion of inertial sensors has helped alleviate this problem for RTK and DGPS auto steer systems.

## The Unbelievable—Autonomous Vehicles

It may seem like some space age dream, but realistically autonomous vehicles are on the horizon. In fact, with some agricultural vehicles the components necessary for autonomous operation are already in place. All we need is the control system. Naturally, the first component is an automatic steering system. As previously described, these systems are currently available and improving. Tractors are being marketed that are capable of memorizing a series of control commands and repeating them with one touch. Integrating this with position information from DGPS and control command prescription map makes the task no more challenging than variable rate application that is currently being implemented. The marketplace will ultimately determine when they become available.

# Pulse Width Modulation to Control Spray Droplet Size for Increased Efficacy and Spray Drift Mitigation

*Robert E. Wolf*

Off-target drift is a major source of application inefficiency. When spraying pesticides, there is always a chance some product will escape from the target area. Drift is a concern because it removes the chemical from the intended target, making it less effective, and depositing it where it is not needed and often not wanted. When a pesticide is applied where it is not wanted, it becomes an environmental pollutant that can injure susceptible vegetation, damage wildlife, and contaminate water supplies. Although drift cannot be eliminated, selecting and using proper equipment can help maintain drift deposits within acceptable limits.

Specific knowledge about crop protection product performance as it relates to spray droplet size will be necessary for future application decisions. Spray droplet characteristics influence the ability of crop protection products to deposit on certain leaf types. If the size of spray droplets can be better controlled then higher efficiencies are expected (Smith et al., 1999). Droplet size produced by the nozzle is a controlling factor in gallonage per acre, target deposition, uniformity of coverage, efficacy, off-target movement, and resulting exposure. Many forces impinge on droplet size, but drop size must be manipulated to optimize performance and eliminate associated undesirable results (Williams et al., 1999).

For normal agricultural spray operations, the flow rate and the consequent volume of application (GPA) are typically regulated through adjustments in pressure and speed or by changing to a different nozzle orifice size. As pressures are adjusted through a given orifice size, the spray droplet size also changes (Womac et al., 1997). With the current abundance of spray machines with electronically controlled application systems, pressure variations can occur rapidly as application speeds change, thus changing the quality of the spray equally as often. Even though the pressure changes are beneficial to maintaining calibrated spray rates, a dramatic change in the spray droplet size emitted from the spray system occurs. For example, to double the flow from a given orifice, a 4-fold pressure increase is required. Thus, in field-spraying situations with electronic controllers, doubling the speed of application requires doubling the flow to maintain the calibrated rate, increasing the pressure 4-fold, and thus resulting in dramatic changes in spray droplet size.

Technology is available to alleviate the problems associated with this scenario. A system using pulse width modulation (PWM) for controlling droplet size while varying application volumes, speeds, and pressure is currently available commercially (Capstan Ag Systems, Inc., Topeka, KS). By maintaining the application volume while adjusting spray pressure, operators are able to manipulate droplet size to meet changing wind and weather conditions or protect sensitive downwind areas. It is also possible to adjust application volumes without changing nozzles or adjusting pressure. This technology also can help maintain pattern uniformity when slowing in turns, for corners, and on hills, thereby preventing overapplication at lower speeds and reducing underapplication during acceleration. However,

adaptation by the industry is slow because the system adds considerable expense to standard spray systems, adequate scientific data supporting the use of the technology does not exist, and exposure to the application industry has been limited.

Management of spray droplet size is a critical issue in the search of accurate and efficient crop protection application systems. In 1992 Giles and Ben-Salem reported the development of a computer-controlled valve attachment for agricultural spray nozzles. The valve system uses an electronically actuated solenoid valve coupled to the inlet of the spray nozzle to provide a variable-duration, pulse spray emission. As first reported, the PWM could modulate flow without distorting droplet size or spray pattern uniformity over a 4:1 range for a given size orifice (Giles et al., 1995). Giles et al. (1996) reported the same response but over a 10:1 flow adjustment. In both reports, a constant pressure was maintained. With the inclusion of PWM for flow control, the speed and pressure affects are minimized, eliminating major variations in droplet size. Thus, high-pressure scenarios normally producing smaller spray droplets with higher drift potential are minimized. Providing a more uniform droplet spectrum should increase field efficacy while drift is minimized (Giles et al., 1996).

The application of crop protection products is an important step in the growing of agronomic crops in our countries economy. A better understanding of PWM should provide the application industry, which includes growers, commercial applicators, agrochemical companies, scientists, and extension personnel, with the information necessary to make the best choices regarding this technology for the application of crop protection products. Future EPA label directives will require applicators to adhere to spray droplet standards (ASAE-572) during application as a means to improve efficacy and minimize drift into sensitive areas.

## References


Giles K and Ben-Salem E. 1992. Spray droplet velocity and energy in intermittent flow from hydraulic nozzles. *Journal Agricultural Engineering Research* 51: 101–112.

Giles K, Henderson G, and Funk K. 1996. Digital control of flow rate and spray droplet size from agricultural nozzles for precision agricultural application, pp 729–738, in *Proceedings of the 3rd International Conference – Precision Agriculture.* American Society of Agronomy-Crop Science Society of Agronomy-Soil Science Society of America. Minneapolis, MN.

Giles K, Young B, Alexander P, and French H. 1995. Intermittent control of liquid flow from fan nozzles in concurrent air streams: wind tunnel studies of droplet size effects. *Journal Agricultural Engineering Research* 62 77–84.

Smith D, Askew S, Morris W, Shaw D, and Boyette M. 2000. Droplet size and leaf morphology effects on pesticide spray deposition. *Transactions of the American Society Agricultural Engineers* 43:255–259.

Williams W, Gardisser D, Wolf R, and Whitney R, 1999. Field and wind tunnel droplet spectrum data for the CP nozzle. American Society of Agricultural Engineers/National Agricultural Aviation Association. Reno, NV. Paper No. AA99-007.

Womac AR, Goodwin JC, and Hart WE. 1997. Tip selection for precision application of herbicides. Univ. of TN Coop. Ext. Serv. Bull. 695.

# Basics and Benefits of Drift Control Agents

*Bryan Young*

## Classification of Products

Herbicide spray drift continues to challenge applicators attempting to make timely pesticide applications. Each year, 120 complaints (on average) of pesticide misuse are reported in Illinois, with 60% of these related to herbicide drift (Illinois Department of Agriculture, 2001). The "damage" associated with herbicide drift can include costs incurred through inefficient use and reduced efficacy of herbicides; damage to sensitive nontarget crops; and lawsuits filed against growers or applicators for damages to sensitive crops and other nontarget organisms beyond property boundaries (Duke, 1997).

Applicators use several methods to reduce spray drift far beyond the basic recommendation of not spraying during excessive wind speeds. Other practices to mitigate drift include reducing spray boom height and spray pressure, increasing carrier volume (allows for larger nozzles), and using a hooded-boom or air-assist sprayer, or a pulse width modulation spray controller. However, a recent survey of Illinois Certified Crop Advisers and producers indicated the two most common methods recommended or implemented for drift mitigation are the use of drift reduction nozzles and drift control agents (Young et al., 2003).

Drift control agents also are referred to as drift retardants and deposition aids. Three main classifications of drift control agents are available to applicators: viscosity agents, inert oil emulsions, and nontraditional. The principle components of viscosity agents are polymers and macromolecules (Elliot and Wilson, 1983), including polyacrylamides, polyethylene oxide, and polysaccharides such as guar and xanthan gums, but the active ingredient and concentration vary from one manufacturer to another (Bouse et al., 1988; Zhu et al., 1997; McMullan, 2000). These compounds function by increasing the surface tension of the spray solution, which increases droplet size and reduces the amount of driftable fines. As the concentration of the drift control agent increases in the spray solution, so does the size of spray droplets. Thus, the rate of some drift control agents, especially the polyacrylamides, can be adjusted for use under different wind velocities or with different nozzle types.

The polyacrylamides refer to a chemical family of drift control agents that were the first to be widely adopted by pesticide applicators and remain the predominant type of drift control agent used today. Even though the basic chemistry is the same, adjuvant manufacturers have continually made improvements to these products for applications with modern herbicide formulations. Hence, these adjuvants should not be considered out-of-date technology.

Hydroxypropyl guar (HPG) is the second most common viscosity agent used and is a fairly recent technology. Products containing HPG may refer to DR2000 or DEPP 775, which are experimental codes for the dry powder and extruded granule formulations of HPG, respectively. The product is essentially the starch extracted from the crop guar.

Some oil-based drift control agents are classified as invert emulsions, meaning an oil film encapsulates

the herbicide. Although a true invert emulsion would require significantly greater concentrations than recommended with current products, these products do incorporate oil, which can influence the spectrum of spray droplets produced and the position of the herbicide in the droplets.

Typically, a simple classification of a new technology is not readily available when the product is first commercialized, as for the nontraditional classification of drift control agents. A recent product is based on lecithin extracted from soybean. Although the product can reduce driftable fines, this product does no alter spray viscosity to the same extent as other products.

A fairly comprehensive, yet incomplete, listing of commercial drift control agents can be found in the *Compendium of Herbicide Adjuvants* (www.herbicide-adjuvants.com). The compendium currently lists 49 drift control agents. The drift control agents are often customized specifically for glyphosate due to the significance of glyphosate in the marketplace and the potential damage to off-target plants from spray drift. For example, ammonium sulfate and defoamer are formulated with a drift control agent in some products to improve the overall application process and glyphosate efficacy.

## Performance of Drift Control Agents

The primary purpose of a drift control agent is to reduce the number of small droplets (driftable fines) that could lead to off-target deposition and damage. The large molecules of the polyacrylamides and HPG undergo pump shear, which is the reduction of the size of the molecules as they repeatedly pass through the pump of an agricultural sprayer. Pump shear reduces the ability of the agent to increase the spray viscosity. Thus, the potential for reducing drift gradually declines each time the viscosity agent cycles through the pump. The polyacrylamide chemistry is typically more prone to pump shear than HPG, but both are susceptible to shear.

Typically, the viscosity agents reduce drift to a greater extent than the invert oil emulsions. However, the manufacturers of the invert oils claim the small driftable droplets do not contain the herbicide, resulting in less potential damage from drift. The benefit of a drift control agent for reducing drift depends on the specific spray nozzle being used. For instance, the addition of HPG to the spray solution reduced spray drift by 19% in a 10-mph wind by using a standard flat fan nozzle (SIU, unpublished data). However, no reduction in drift was observed with HPG when a venturi style (air induction) nozzle was used under the same conditions. The nozzle was already reducing drift more than the potential of the drift control agent. This observation may or may not be true at wind speeds greater than 10 mph.

So why use a drift control agent if using a drift reduction nozzle can reduce drift to a greater extent? The large droplets produced from drift reduction nozzles can reduce the retention of spray droplets on target leaves. A large droplet may create too much splash on impact with target leaves, which can reduce the amount of spray retained on the leaf or the quality of the final spray deposit. Likewise, a large droplet may fall off the leaf surface, especially if the droplet coalesces with dew on the leaf surface during early morning applications or if the leaf of the target weed is difficult to wet. The use of drift control agents may have benefits other than mitigating drift, such as increased spray retention, reduced splash (anti-bounce), and enhanced herbicide uptake on some weed species (Downer et al., 1995). For example, glyphosate spray retention on giant foxtail was increased with the use of a drift control agent (Downer et al., 1997).

The performance of the herbicide application in response to the addition of a drift control agent can vary anywhere from a reduction to an increase in weed control. The exact response is difficult to predict as the efficacy of the herbicide application would be dependent on the specific target weed, weed growth stage and condition, carrier volume, nozzle type, environmental conditions, and the specific drift control agent and rate. Using a drift control agent that results in larger droplets and less spray coverage to a weed species that is already difficult to control for the herbicide would be the worst-case scenario. For example, reductions in control of common waterhemp with glyphosate have been observed with the combination of drift reduction nozzles and drift control agents (Fietsam and Young, 2001). Special attention should be given to spray coverage when using drift control agents. If coverage is drastically reduced, make sure that all other factors involved with the application are close to ideal for herbicide activity to avoid any unnecessary reductions in weed control.

Drift control agents continue to evolve with new functioning agents or product concepts for use with specific herbicides. Drift control agents are a valuable tool to minimize herbicide drift. Although these agents are not as effective as nozzles for managing drift, the products can still improve herbicide performance by enhancing the amount and quality of the final spray deposit.

## References


Downer RA, Ebert TA, Thompson RS, and Hall FR. 1997. Herbicide spray distribution, quality and efficacy interactions: conflicts in requirements. *Aspects of Applied Biology* 48:1–9.

Downer RA, Wolf TM, Chapple AC, Hall FR, and Hazen JL. 1995. Characterizing the impact of drift management adjuvants on the dose transfer process, pp 139–143, in *4th International Symposium on Adjuvants for Agrochemicals*. Melbourne, Australia. 3–6 October. FRI Bulletin 193.

Duke SO. 1997. Will herbicide resistance ultimately benefits agriculture?, in *Weed and crop resistance to herbicides* (De Prado R, Jorrin J, and Garcia-Torres L eds.) pp 323–331. Kluwer Academic Publishers, Boston.

Fietsam JF and Young BG. 2001. Combined influence of drift reduction nozzles and agents on glyphosate efficacy. North Central Weed Science Society Abstract 56:143. [CD-ROM Computer File].

Illinois Department of Agriculture. 2001. http://www.agr.state.il.us/Environment/Pesticide/pestuses.html. Accessed: October 12, 2003.

Young BG, Schmoll KL, Steffen RW, and Moon W. 2003. Survey of herbicide drift in Illinois. Weed Science Society of America Abstract 43:234.

# Herbicide Behavior in the Soil Environment

*Bill Simmons*

Herbicides with soil activity are still an important component of weed control in corn and soybean. Such herbicides may include both pre-applied herbicides and post-applied herbicides. The interaction of soil properties, water, and application timing affects the fate and behavior of herbicides, crop response, and potential for carryover. In this presentation, I discuss the following topics: the basics of soil interactions with herbicides; the value of residual control in total POST systems; soil pH effects on carryover and in-season injury; behavior of "new herbicides" in the soil; carryover potential as affected by herbicide, soil, and climatic conditions; and time–dissipation relationships for fall-applied herbicides.

Soils contain the organic matter and clay particles that control herbicide sorption, water relations, and provide the environment that influences microbial activity. The primary herbicide loss pathways in soil are microbial breakdown and chemical breakdown, primarily driven by reactions with water. The affects of soil temperature and moisture on herbicide degradation are straightforward in that degradation mechanisms that involve microorganisms operate best at optimum biological growth conditions. In addition, nonbiological chemical reactions are typically enhanced with increased temperature. Water is essential for microbial activity and increases aerobic processes up to the point that saturation occurs and gas transfer with the atmosphere is hampered. Soil texture and organic matter content have a surprisingly small effect on carryover because the differences in water and nutrient availability are often counterbalanced by the difference in herbicide adsorption. Thus, a fertile soil, rich in organic matter may promote faster degradation of a herbicide but also have less available to degrade based on its greater adsorption sites.

Soil pH is important in affecting the stability of some herbicides and herbicide families. High soil pH associated with calcitic soils, over-liming, or proximity to limestone gravel lanes may reduce herbicide degradation and increase carryover. This effect may be important for triazines and some sulfonylureas. Hydrolysis, an important breakdown mechanism, slows significantly at soil pH values near 7.0.

Biopersistence, or the ability of the parent compound to exist in the soil, is an important feature of soil-applied and some postemergence herbicides and determines the suitability of early preplant applications, residual weed control, and threat of off-site loss to surface or groundwater. To optimize the application timing of soil-applied herbicides a balance between persistence and requirement for rainfall needs to be considered.

The soil-applied acetamide herbicide market in corn is still a significant and competitive marketplace where performance profiles across application timings determine use and market share. In the past few years, several new herbicides have been introduced; Define (flufenacet) by Bayer Corporation, Degree (encapsulated acetochlor) by Monsanto, and most recently several formulations containing mesotrione (Callisto and Lumax). Dual Magnum is the active isomer of metolachlor and allows for a lower use rate than the "old" Dual. BASF also has purified an active

isomer of dimethenamid (Outlook) that allows its use rate to be lowered while obtaining the same efficacy. These developments are the most recent ones in the marketplace. Future changes in the use patterns of these herbicides may occur in transgenic corn, in mixes with isoxaflutole and similar herbicides, and in formulations that allow postemergence application of these herbicides.

Herbicide persistence is an important property of soil-applied herbicides and some postemergence herbicides that allows for extended weed control. When the herbicide remains unaltered in the soil during the crop season of application, it is an advantage. If a herbicide remains in the soil and is present when a rotational (and susceptible) crop is planted the persistence causes herbicide carryover. Most herbicides ***do not*** *carryover. Degradation rates in the soil under normal environmental conditions typically reduce herbicide concentrations to sublethal levels for rotational crops. Some herbicides have additional safety in that they are not injurious to rotational crops.*

Shifts in herbicide application timing to earlier applications have put a premium on herbicide persistence to coincide with weed emergence. In a broad sense, the resistance to degradation and downward movement within the soil profile are both important to obtaining satisfactory weed control.

Glyphosate-resistant soybean treated with glyphosate alone does not allow for any residual control of weeds that might emerge after the last POST application is made. What is the value of a residual herbicide either mixed in with glyphosate or applied to the soil at planting? Data are presented that address this issue.

# Corn Diseases and their Management

*Gary P. Munkvold*

Corn is a crop that could serve as a model for the effectiveness of disease management by genetics. Few other crops can boast of useful levels of resistance against such a broad range of diseases. Nevertheless, diseases continue to pose a management challenge, for several important reasons:

- Corn hybrid development involves a difficult balance of many priorities
- Profit margins in corn production are low
- Fewer producers are managing more acres
- Shifting cultural practices affect the prevalence of specific diseases
- Disease prevalence constantly changes because of other influences, not always understood
- Market specialization creates different criteria for disease management

Because of these challenges, there are always unresolved, economically important disease problems. Several of these are caused by fungi that are opportunistic pathogens of several corn plant tissues:

- *Gibberella zeae*—stalk rot, ear rot, and seedling disease
- *Stenocarpella maydis*—stalk rot, ear rot, and seedling disease
- *Fusarium spp.*—stalk rot, ear rot, and seedling disease
- *Colletotrichum graminicola*—stalk rot and seedling disease

Plant disease management can be characterized by cultural, chemical, and genetic methods. For the stalk and ear rot diseases, chemical control has not been efficient enough to be implemented. Therefore, producers must rely on the genetic and cultural methods. Genetic resistance is an important component of the management strategies for all four of these fungi, but usually, there has been little definition to the cause of this resistance. These diseases are subject to strong, sometimes overwhelming, interactions with the environment, which has hindered both selection for resistance and identification of sources of resistance. The sporadic occurrence of stalk and ear rot makes it difficult to obtain reliable data yearly that can be used to differentiate hybrids. For stalk rots, it is unusual for a field or research plot to be attacked by a single pathogen, which also has been a major obstacle in the development of hybrids resistant to specific stalk rots.

Cultural practices are well known determinants of disease severity, yet other forces often drive the changes that producers make in their cultural practices. Some of these changes can be counterproductive in disease management. Recent changes or continuing trends include

- Reduced tillage
- Earlier planting
- Higher plant densities
- Larger equipment

When "specialty" markets for commodity crops emerge, there can be additional disease concerns that are different or more acute than the concerns for a bulk commodity. Corn grown for human food is one

example. In food corn, the spectrum of disease concerns is not greatly different from that of bulk grain producers, but the level of ear rot disease that can be economical in food corn is much lower than that typical for bulk grain. The increased emphasis on grain quality and potential mycotoxin contamination necessitate a keener eye toward ear rot management. At the same time, if hybrids are to be developed specifically for the food market, they must meet other criteria for grain characteristics that are desirable for food processing. These requirements add another layer of complexity to hybrid development: hybrids must be high-yielding; able to endure a variety of environmental stresses while maintaining yield and stalk integrity; and have acceptable resistance to leaf diseases, stalk rots, and insect pests; good resistance to ear rots; **and** grain characteristics that maximize their suitability to milling.

The success of potentially profitable specialized market segments sometimes requires a new way of thinking about established crop management practices. The quality expectations in food corn require a careful integration of cultural and genetic disease management tools, especially for the ear rot diseases. This approach can best be accomplished through good lines of communication among growers, processors, and seed producers.

# Retail Seed Treatment 101

*Mark Miller*

During the past 5 years, several seed dealers throughout the Midwest have been offering custom applications of fungicide seed treatments to their seed customers on wheat and soybeans. The factors that have helped them make the decision to offer custom seed treatment are 1) increased demand for treated soybean seed, 2) allowing growers to delay variety and treatment decisions until planting time, and 3) the ability to increase services and value to their customers. This market segment has centered on soybean fungicides as growers learn the value and insurance of planting seeds that are protected from early season seedling diseases.

With expected registrations of new seed treatment insecticides, along with fungicide seed treatments and inoculants for soybeans, many retail seed locations are considering the addition of custom applications of seed treatments to their business. There are several factors to consider before making a final decision to determine whether seed treatment fits your business. Once the decision is made, you need to determine the necessary steps to ensure success at your location. This session is intended to explore these factors to help you make the best decisions and increase your level of success.

A good starting point is to determine your potential market for treated soybean. There should be the potential for at least 5,000 units of seed in the first year to cover the costs of equipment and labor. Second- and third-year sales should be expected to double or triple to provide a sustained level of profitability. Your seed treatment sales representative can assist in helping you assess your potential sales.

Equipment is the largest single cost of starting up a seed treatment business. The seed treater is the center of your seed treatment setup, but other handling equipment and space requirements should be taken into consideration to get the best fit for your location. Start by thinking about how soybean seeds are currently handled at your location. If you are not working with bulk seed, you should consider doing so. Many locations are breaking 50-pound bags just before treatment but this approach increases labor costs.

Most likely, the seeds will need to be lifted high enough to allow them to enter the seed treater and then again to get them into your customer's bulk transport equipment. Use conveyors not augers. Seed damage from augers has been well documented by university research. Seeds damaged in handling equipment do not recover with a seed treatment.

Now you are ready to consider the seed treater. The seed treater is required to meter seeds and seed treatments at the same time and bring them together so that all seeds are evenly covered. There are several seed treaters available for use at the retail level. Buy the best you can afford. Although some seed treaters feature lower purchase cost, they may lack features that simplify the seed treatment application or the accuracy with which it is made. Although you probably have more time in the winter when most equipment decisions are made, remember that time is often in short supply during the planting season when most

retail treatments occur. Extra features make the process more efficient. If there are features you would like but are not offered, call the equipment maker and ask whether they can modify or add the feature. Most likely they can. Many manufacturers of seed treatments have incentive programs that can help with the purchase price of your seed treater. These programs are usually multiyear; consider how they could affect your business throughout the entire contract period.

The following are essential components of the seed treater:

- **Mix tank.** Unless you are using a Ready-To-Apply seed treatment, you need to add water along with the seed treatments and keep them well mixed.
- **Seed meter.** You need to know how many pounds of seed are moving through the treater in 1 minute. Without this knowledge, an accurate application is unlikely. Seed treaters at the retail level control seed flow by the use of a restriction in the flow of the seeds. You need to calibrate this flow so that you can determine the correct amount of liquid seed treatment to apply.
- **Chemical pumps and meter.** These components control the rate of the chemical application. Make sure that the unit you choose has reliable pumps and a quality method to control the flow. If you overapply, you are "giving profit away," whereas if you underapply, you could experience poor field performance. Check your calibration often.
- **Primary application.** Primary application refers to the area where the seed and chemical first meet. Equipment that atomizes the chemical into the seed flow is preferred because it allows for a quality treatment with lower slurry rates. Lower slurry rates allow the treated seeds to dry faster.
- **Secondary application.** Secondary application refers to the area where the seed treatment is finished by allowing the seed treatment to flow over the entire seed surface. This application usually is done in a rotating drum or seed ladder. A lower quality primary application requires the seed treater to rely more on the secondary mixing to accomplish the desired coverage.

There are some state and federal requirements that need to be met for proper seed treatment. They are not difficult or complicated but cannot be overlooked. Most states require any person performing custom seed treatment applications to be certified by taking a state certification exam. Check with your state's Department of Agriculture for specific requirements.

Secondary containment requirements also need to be considered. Most likely, you need to dilute the seed treatment products to make a slurry before application. You need a proper mix tank for this process, and most state laws require this mix tank to be protected by some form of containment. The mix tank may be small enough to be exempt from this requirement, but it is still a good idea.

The Federal Seed Act requires that treated seeds be labeled with chemicals applied, along with any restrictions that may apply. This information is for the grower and others using the seeds. Although you will be performing a custom application after the grower has selected the seed treatment and the seeds will be in bulk, it is still a good idea to have a written document to provide to the grower. You can get the specific information required from the seed treatment label or just ask your seed treatment distributor.

# Management of Forages for Better Yield and Profit

*Rich Leep and Dean Malvick*

Forages as opposed to row crops are harder to measure for yield. Additionally, forage quality affects profitability of the crop. Several management factors can affect both yield and profitability of forages, whether it is alfalfa haylage or a pasture composed of a complex mix of grasses and legumes. In this presentation, we cover management factors of some forages crops that seem to be the overriding influence upon yield and profitability of forages.

Alfalfa is one of the most important forages grown in the North Central region, which grows 57% of the 24 million acres in the United States. A recent survey of Michigan dairy producers found the average cash (e.g., seed, sprays, fertilizer, labor, repairs) and noncash costs (e.g., unpaid labor and depreciation) for seeding and maintaining a 4-year stand (including seeding year) was $397/acre. The average cost per ton of 35% dry matter haylage was $35.83 based upon an average yield of 12.9 tons/acre of 35% dry matter haylage during years 2–4. Growers in this study whose yield was 15% less than the average yield resulted in costs per ton of haylage of $42.15. This difference may not seem like much; however, when using sensitivity analysis of a yield loss of 15% when the alfalfa is being fed to a 100-cow dairy herd in Michigan would have resulted in a loss of profit of $8,100/year. **When applying this same scenario to an alfalfa cash crop farm, the 15% lower yield would amount to a loss in profit of $82.00/acre/year.** The interesting point that can be gleaned from these financial data on Michigan dairy farms is that management factors are what contributed to higher or lower yields. Those factors that contributed to higher yields included using university and company variety testing results in choosing high-yielding varieties with adequate winter hardiness, soil testing to optimize fertilization, and obtaining good stands. In addition to the above-mentioned factors, the growers getting higher yields and forage quality were using harvest prediction tools such as growing degree days and "PEAQ" sticks to help them decide when to cut their alfalfa for proper forage quality. The fact remains that everyone producing forage for profit must know what their yields are for every field to determine what their cost of production is on an acreage and per ton or bale basis. Knowing the yield becomes a useful tool in evaluating true costs of producing forage. Once yield is known, a grower can begin looking at other management factors such as variety selection, fertility, harvest, and insect and disease management for the crop.

Soil sampling plays an important role in management of alfalfa and other forages. Most local extension offices have bulletins on how to take a good representative soil sample. Often, producers do not put enough emphasis on this simple procedure, which is used as the basis for what fertilizer recommendations are being made for a 3–4-year period of production. A poor soil sample results in erroneous recommendations that can be costly if fertilizer is under- or overapplied. Using past cropping history and field usage as well as soil differences should be considered when sampling fields to be planted. A recently completed study in Michigan comparing grid sam-

pling at 2-acre grid patterns compared with conventional soil sampling on a 25-acre alfalfa field on a participating dairy farm showed that the farm was both over- and underapplying potassium and phosphorus to the alfalfa crop within the field. It seems that the highest yielding portion of the field was essentially mining the field of nutrients, whereas the lower yielding portions were resulting in a build up of both potassium and phosphorus. Using sensitivity analysis, we estimated the difference in fertilizer costs comparing grid soil sampling and variable rate fertilizing with conventional soil sampling and fertilizer spreading was $856 versus $1,300/year after deducting the extra costs of grid sampling and variable rate spreading technology. Adding lime far enough ahead of planting alfalfa for the liming particles to react to the soil is also important for obtaining good stands and plant persistence. Proper drill calibration before planting results in better stands. Remember, all alfalfa or other forage seed is not always the same size because size depends upon the growing conditions of seed as well as the use of seed coating. Even coated seed flows differently between brands of coatings.

Pastures are often the least managed of all forage crops produced. Almost always, the profit potential of a pasture-based operation depends upon managing the pasture for high yields and as long a grazing season as possible. This approach includes choosing species that compliment the soil recourses available as well as choosing species with value added traits, including quick recovery, deeper root systems, and ability to grow later into the fall for longer grazing periods. In doing so, careful management for maintaining legumes in the stands produces extra benefits, including less need for nitrogen fertilizer and better gains or milk production from grazing animals.

What species are best for my pasture? The answer is determined by the forage quality needed by the grazing animals. Additionally, it depends on the natural soil drainage and soil pH. Each species of legume requires different soil pH and drainage characteristics. What species are best for renovating or interseeding into pastures for thickening stands? Legumes differ in both seedling vigor and their ability to tolerate shade, which influences success in establishment into existing pastures. Red clover is the most shade-tolerant legume followed by followed by birdsfoot trefoil, white clover, and alfalfa. Red clover exhibits the greatest seedling vigor followed by alfalfa, white clover, and birdsfoot trefoil. The most vigorous grass species for renovation is ryegrass followed by orchardgrass, smooth bromegrass, tall fescue, and timothy.

Whether to apply and how much nitrogen to apply are common questions asked by producers who want to get the most out of their cool-season grass pastures. Some guidelines should be used to determine whether there will be a financial payback from the fertilizer nitrogen on pastures. Fertilizer nitrogen should not be applied to pastures that are comprised of 30% or more legumes because legumes fix nitrogen from the atmosphere through dinitrogen fixation. Some of the nitrogen that is fixed by legumes in this manner is used by grasses grown in association with legumes. In addition to the nitrogen made available to grasses from legumes, there is usually a higher yield associated with the grass–legume combination compared with grass growing alone. Forage quality in terms of higher crude protein and lower neutral detergent fiber (NDF) levels also are associated with legumes growing with grasses compared with grasses growing alone. In a study established in 2001 at the Kellogg Biological Station in southern Michigan, the average yield of cool-season grasses grown with kura clover, red clover, or white clover was 4.0 tons/acre, whereas the average yield of the same grasses grown without clovers but with 200 lb/acre actual nitrogen was 3.5 tons/acre. The average yield of the clovers grown alone was 3.2 tons/acre. These data point out the clear advantage of growing grasses and legumes together. If a pasture is less than 30% legume content, growers should consider improving the pasture with either no-tillage or frost seeding legumes such as red or white clovers.

Grass species differ in their potential to use applied fertilizer nitrogen. Festulolium, perennial ryegrass, and tall fescue normally use applied nitrogen fertilizer more efficiently than orchardgrass, Timothy, and smooth bromegrass. In a study established in 2001 in East Lansing, MI, we evaluated the effect of increasing nitrogen application rates upon the dry hay yield of grass grown without legumes. The results of this study confirmed that species differ in their ability to use nitrogen. Hay yields of perennial ryegrass (diploid), festulolium, and orchardgrass were increased with added fertilizer nitrogen up to 200 lb/acre applied in split applications of 50 lb/acre four times during the growing season. Additional fertilizer nitrogen applied above 200 lb/acre for those species resulted in no significant increases in yield. Nitrogen rates up to 300 lb/acre increased the yield of both tall fescue and tetraploid perennial ryegrass. However, more winter injury occurred with nitrogen fertilizer rates above 200 lb/acre in the perennial ryegrass and festulolium species. Crude protein increased significantly with increasing nitrogen rates up to 200 lb/acre. NDF fiber was not affected by nitrogen fertilization applications to the grasses. The effect of increasing rates of nitrogen fertilizer on ground cover was not significantly different between species of grasses. However, the diploid perennial ryegrass generally had

higher ground cover compared with the other species of grasses studied.

As noted above, diseases can reduce forage yield and quality, thin or destroy stands, decrease stand persistence, and increase susceptibility to winter kill and other environmental stresses. Diseases result from the interactions between susceptible forage varieties, pathogens, a conducive environment, and occasionally from improper crop management practices. Some of the major diseases of alfalfa in the Midwest include anthracnose, Aphanomyces root rot, bacterial wilt, Fusarium wilt, leaf diseases, Phytophthora root rot, Sclerotinia crown and stem rot, and Verticillium wilt. Common clover diseases include anthracnose, Aphanomyces root rot, leaf diseases, Fusarium root rot, powdery mildew, Sclerotinia crown and stem rot, and clover yellow mosaic virus. Forage grasses are commonly affected by stem and crown rust. The first step in managing forage diseases is prevention through proper site selection and field management practices as discussed above. The second critical step for managing many important diseases of forages is selection of disease-resistant varieties adapted for the area where they will be planted.

Clearly, there are many management factors that can give a large return for the investment. Some practices really do not require additional costs but do require some thinking and planning on the producer's or manager's part. It is often these managers who consistently earn more net farm income from their operations.

## References for Forage Management

### *Web sites*


http://www.msue.msu.edu/fis/
http://cropdisease.cropsci.uiuc.edu/alfalfa/
http://www.uwex.edu/ces/forage/
http://www.uwex.edu/ces/crops/uwforage/FocusonForage.htm
http://www.hayandforage.com/
http://www.rce.rutgers.edu/horsepastures/index.html
http://www.forages.psu.edu/topics/index.html
http://www.plantmanagementnetwork.org/cm/


The following extension bulletins can be purchased online at http://web2.msue.msu.edu/bulletins/subjectsearch.cfm

- Alfalfa Management Guide, Extension Bulletin NCR-547
- Steps to Successful No-till Establishment of Forages, Extension Bulletin E2880
- Perennial Legume & Grass Variety Selection for Michigan, Extension Bulletin E-2787
- Buying Horse Hay, Extension Bulletin E-2804

# Identification and Management of Winter Annual Weed Species

*Mark M. Loux*

## Nature of the Problem

Winter annual weeds have become increasingly problematic in agronomic crop production over the past several years. Several winter annual weed species that may have only infrequently infested fields 10 years ago are now present in uniformly dense populations across many fields in the spring. These species include common chickweed, purple deadnettle, henbit, horseweed, and cressleaf groundsel. The populations of biennial and perennial weeds such as wild carrot, common burdock, and dandelion also have increased in many areas.

Winter annual weeds typically emerge in late summer through fall, overwinter in the vegetative stage or as a rosette, and flower and produce seed in late spring or early summer. Exceptions to this cycle can be found, because some winter annuals can emerge in the spring (e.g., common chickweed and horseweed), and some maintain vegetative growth through late summer before flowering (e.g., horseweed). Winter annuals directly interfere with wheat establishment and growth in the fall and spring. Although they do not necessarily compete directly with corn and soybean growth, winter annuals cause a number of other problems, including the following:

- the dense mat of chickweed and other winter annuals can slow soil drying and warming and interfere with tillage and crop establishment in the spring;
- winter annuals may harbor insects in the spring, which later infest corn or soybean; and
- purple deadnettle and several other winter annuals seem to serve as alternate hosts for soybean cyst nematode.

Proper identification of winter annual weeds is essential for selecting a herbicide-based winter annual management program. Fields can be scouted in the fall to determine the species of winter annual weeds present. More often, however, producers become aware of winter annual weeds around the time of crop planting in spring, when they are more easily identified. Fields densely populated with winter annuals in the spring are candidates for herbicide treatments the following fall, or early enough the following spring to prevent problems and additional seed production. It is also essential to know whether perennial weeds such as Canada thistle and quackgrass are present in a field, because these weeds are likely to require the use of glyphosate. Fields with primarily winter annual weeds can be treated with a number of different herbicides and do not necessarily require use of glyphosate.

## Management Strategies for Winter Annuals

The goals of a winter annual weed management program should be control with herbicides or tillage in the fall or early spring to 1) prevent interference with crop establishment and early season growth; 2)

reduce populations of insect or other pests associated with winter annuals; and 3) prevent additional winter annual weed seed production. For horseweed, which has a longer life cycle than most other winter annuals, an additional goal should be residual control through early June to prevent interference with corn and soybean growth. Control of winter annuals by late fall can be important in winter wheat, to prevent interference with wheat growth in early spring and to ensure development of a healthy wheat stand.

## Fall Herbicide Treatments or Tillage

Application of herbicides in fall is an extremely effective tool for managing winter annual weeds, and fields where these weeds have been a problem over the past several years should be considered candidates for fall herbicide treatments. Tillage in late fall also controls emerged winter annual weeds, but most types of tillage do not adequately control dandelion. Most of the fall herbicide treatments in Ohio State University (OSU) research trials have been applied in early to mid-November, but occasionally as late as early December. We generally suggest the window of mid-October to mid-November for optimum control of winter annual weeds and dandelion. Fall application of Harmony Extra in wheat must be delayed until the wheat has reached the two-leaf stage.

Although a number of herbicides can be applied in the fall, the most effective treatments in OSU research where winter annuals and dandelion have been present have included glyphosate (0.75 lb ae/acre), glyphosate (0.38 lb ae/acre) plus 2,4-D (0.5 lb ae/acre); and CanopyXL (2.5–4.5 oz/acre) plus Express (0.1–0.2 oz/acre) plus 2,4-D (0.5 lb ae/acre). 2,4-D applied alone does not control common chickweed and is approximately 20% less effective for dandelion control compared with the previously mentioned treatments. An advantage of using herbicides with residual activity in fall treatments, such as CanopyXL and Sencor, is the control of spring-germinating winter annuals. This consideration can be important for common chickweed and horseweed, which can emerge in spring and behave as summer annuals under certain environmental conditions.

Fall application of residual herbicides also can control summer annuals, such as lambsquarters and velvetleaf, into late spring or early summer, or until the time of postemergence glyphosate application in Roundup Ready soybean. The length of control of summer annuals varies by species, herbicide rate, and density of weed population. We had consistent populations of lambsquarters and giant ragweed in several studies where herbicides were applied last fall in west central Ohio, and we were able to get a better idea of residual control of these weeds. We also observed a substantial amount of spring-emerging chickweed and evaluated herbicide effectiveness on this weed as well. Herbicides were applied November 8, 2002, and control data shown below are from a May 28 rating. Treatments containing just glyphosate or glyphosate plus 2,4-D are not included herein because they did not provide any residual control, although they effectively controlled weeds that had emerged by early November. Chickweed control ratings reflect both fall and spring control, so treatments that controlled emerged chickweed in the fall but provided no residual control still ended up controlling approximately 50% of the total chickweed that was present in May. All treatments included 2,4-D ester and/or glyphosate unless otherwise noted, so these results reflect differences in residual control only. (Key: CC, common chickweed; LQ, lambsquarters; GRW, giant ragweed [very high population]).

Sencor (8 or 10 oz): CC, 63%; LQ, 3%; GRW, 0%
CanopyXL (2.5, 3.5, or 4.5 oz): CC, 98%; LQ, 100%; GRW, 78%
Python (1 oz): CC, 70%; LQ, 20%; GRW, 13%
FirstRate (0.3 oz): CC, 55%; LQ, 50%; GRW, 63%
Backdraft (5 pt): CC, 58%; LQ, 23%; GRW, 23%
Valor (2 oz): CC, 58%; LQ, 70%; GRW, 6%
Simazine (1 lb ai): CC, 77%: LQ, 11%; GRW, 16%
Basis (0.33 oz): CC, 77%; LQ, 17%; GRW, 20%

## Spring Herbicide Treatments

Although not as consistently effective as fall treatments, spring herbicide treatments can achieve the goals of preventing problems with crop establishment and preventing additional winter annual seed production. However, they must be applied fairly early in spring and have rapid activity on emerged weeds, so that the weeds are dead and preferably completely desiccated within a short period. Slow herbicide activity in spring often results in a failure to eliminate the dense mat of chickweed and other winter annual weeds well ahead of planting, which is a primary goal of winter annual management programs. Systemic herbicides such as 2,4-D, glyphosate, and chlorimuron have been more consistently effective when applied in the fall, compared with spring. The rate of activity of spring-applied (late March) glyphosate on chickweed has been variable in OSU research, and glyphosate rarely provides complete control of purple deadnettle by the time of crop planting. We have observed more rapid control of winter annuals with contact herbicides in the spring, and especially with combinations of atrazine or Sencor with paraquat. These combina-

tions may be less effective than systemic herbicides in fall, but they are more effective in spring when systemic herbicide activity is slow.

One advantage of application of herbicides in spring versus fall is the length of residual activity on horseweed and summer annual weeds. When the goal is to control weeds for as long as possible after crop planting to create flexibility in the postemergence application window, spring application of residual herbicides often has a better fit than fall application. In a study we conducted over the past 3 years, we applied various herbicides in the fall and early spring to determine the length of residual control of horseweed (marestail). In the 2001–2002 study (acetolactate synthase [ALS]-resistant site), most fall treatments were providing at least 90% horseweed control in early May. However, differences among fall treatments were evident by early June, which indicates that much of the spring emergence of horseweed can occur in May. Perhaps the clearest indicator of these differences was the measurement of horseweed population densities, which in early June were as follows for fall applications (in number of plants per square yard): untreated,130; Canopy XL (5.8 oz), 78; glyphosate, 61; Valor (2.5 oz), 55; Python (1 oz), 47; FirstRate (0.6 oz), 44; Authority (6.4 oz), 17; Scepter (2.1 oz), 13; and Sencor (8 oz), 13. In contrast, application of Canopy XL, Valor, Sencor, FirstRate, or Authority in early April resulted in five or fewer horseweed plants per square yard by early June.

In the 2002–2003 study, where the horseweed plants were less numerous and the population was not ALS-resistant, fall-applied herbicides were more effective than in the previous year's study. Horseweed population densities in early June were as follows for fall applications (in number of plants per square yard): untreated, 52; glyphosate, 16; Sencor, 12; Scepter, 12; Python, 8; Authority, 4; Canopy XL, 0; Valor, 0; and FirstRate, 0. Early April application of herbicides resulted in complete control of horseweed through early June for all treatments except Python, for which a population of four plants per square yard was observed.

## Remediation Versus Prevention: Long-term Strategies

One of the immediate goals of a winter annual management program should be preventing production of additional seed, to reduce future infestations. Due to a relatively short seed life in soil, populations of winter annuals can be greatly reduced with an aggressive management strategy within a few years. Fall herbicide treatments are probably the most consistently effective means of controlling dense populations of winter annuals and reducing seed production. Once the population of winter annuals has been reduced, fall herbicide treatments may no longer be needed, if the winter annuals are properly managed in spring. Proper management in spring consists of two components: 1) control of emerged winter annuals early enough to prevent seed production; and 2) use of herbicides with residual activity to control winter annuals that can emerge in late spring or early summer, such as chickweed and horseweed. The low-cost weed control strategy used by many soybean producers at this time, where glyphosate is applied once or twice beginning at or after soybean planting, is not likely to adequately prevent winter annual seed production. A more effective, but possibly higher cost strategy would be the application of residual herbicides (CanopyXL, Sencor, Valor, etc.) plus 2,4-D and/or glyphosate in early to mid-April.

# Managing the Process of Seed Production for Product Purity

*Barry Martin*

## Foundation Seed Development

- Purity of Foundation or Parent seed is the primary step and is essential for final product purity
- Foundation seed nomenclature varies by crop and geography; however, the principles are very similar.
- The primary process steps are
  - Breeder seed or pre-basic, hand pollinated
  - Generation 1 or basic seed is the first generation of sib or open-pollinated seed
  - Generation 2 or certified is the second-generation increase of basic seed

## Breeder Seed (Pre-Basic or Pre-Foundation)

- Managing the hand-off of seed from plant breeders to production is a key feature of ensuring product purity
- Seed from individual plants is planted in field rows to examine new lines for phenotypic uniformity
- Seed from individual plants also may be tested using protein and DNA analyses, or analytical tests for other constituents are performed at this stage
- Seed is produced by hand pollination or is isolated from insects, if needed, to ensure self-pollination
- In seed bank maintenance, seed is maintained in ear-row format; self-pollination provides mechanism that forces trait segregation; results in maintenance of nonsegregating inbred lines

## Basic Seed, Generation 1 (Foundation or Parent Seed)

- Seed is planted in a bulk from Breeder Seed rows, which were uniform for phenotypic, biochemical, and protein or DNA tests
- Fields are rotated to prevent emergence of plants from a previous crop and are isolated to prevent wind or insect movement of pollen into the fields from other varieties of the same species; isolation distance varies by crop, geography, certification standards, and Biotech Trait content
- For outcrossing species such as *Zea mays*, 640 feet or 200 m is considered a minimum isolation
- For development of parents for hybrids in insect-pollinated crops such as oil seed rape or canola, isolation distances of greater than 1 mile can be necessary to ensure purity
- Fields are rouged to ensure freedom from accidental outcrosses and/or off types
- Observation of plant phenotype through the season and harvest are necessary to ensure purity
- Harvest, handling, drying, conditioning, and packaging of seed must be designed to prevent mixtures from other crops and other varieties of the same crop
- Postharvest testing on appropriate numbers of seed need to be arranged to ensure purity

## Foundation, Generation 2

- Seed purity of generation 1 seed used to plant generation 2 foundation field must be rigorously tested using grow outs, biochemical and DNA tests, and analytical tests, if required, to ensure purity
- There is no reason why generation 2 seed cannot be used if good isolation is used
- In maize, this has led to increased use of Washington and California for foundation seed production in maize

## Commercial Seed Purity

- Key factors for production of high-purity cross-pollinated crops are
  - Adequate pollen control of female either solid cytoplasmic male sterility system or detasseling
  - Adequate pollen volume and delivery from male to female plants (insects or wind) at the time when plants are receptive to pollen
  - Isolation from foreign pollen
  - Crop rotation to limit volunteers and good rouging to remove off-type plants from the field

## Commercial Seed Purity—Harvest, Handling, and Conditioning

- A good quality management system such as ISO9000 necessary to ensure good process control
- Avoidance of seed mixture is important at each transfer of seed, field to receiving to drying, shelling and bulk storage and bagging

## Quality Assurance Seed Testing

- Laboratory testing does not improve purity but can be a determinant of how a seed lot is used
- Varietal purity and labeling affects purity required; in pure line varieties, purity is stated on the tag
- Maize hybrids must be at least 95% hybrid; therefore, this level is the de facto purity level; in this case, selfs plus outcrosses must be less than 5%

## Quality Assurance Genetic Purity Testing

- Grow outs were the first seed purity test and are still the official measure of purity; in these tests, appearance of plants is used to gauge purity
- Isozymes are used in many crops as an early indication of selfs, outcrosses, or mixtures and are used extensively in maize, canola and canola/oilseed rape (OSR) and sunflower hybrid testing
- Seeds that contain biotech traits are often tested using enzyme-linked immunosorbent assay or laminar flow methods such as "dip sticks" to determine presence or absence of a trait
- Herbicide-resistant crops are tested by towel testing in presence of the herbicide
- Testing for adventitious presence by using DNA tests such as polymerase chain reaction can be used to determine whether unintended traits are in a product

# Biotechnology Enforcement

*Karen Heisler*

Enforcement is one strategy among several that may be used by the Federal agencies charged with regulating products derived through biotechnology in order to carry out our missions. Compliance oversight and enforcement need to be considered in their statutory and regulatory context to help to clarify their purposes and goals. This discussion focuses on compliance oversight and enforcement by the Environmental Protection Agency (among the three federal agencies that participate in biotechnology regulation) as it pertains to biotechnology products, and the agency mission and mandate to protect the environment and human health.

## The Coordinated Framework

Three federal agencies share the duty of regulating products derived from biotechnology according to the Coordinated Framework that was formulated and advanced by the White House Office of Science Technology and Policy and the relevant agencies in 1986. This approach is anchored in a logic of regulating products and not the processes of their production systems, and relies on existing statutes and associated authorities of three agencies.

- The Food and Drug Administration (FDA) assesses food safety and nutritional aspects of new plant varieties. FDA bases its biotechnology policy on existing food law and requires that genetically engineered foods meet the same safety standards required of all other foods.
- The United States Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) uses the authority of the Plant Pest Act to fulfill their responsibility to protect American agriculture against pests and diseases. APHIS regulates the field testing of genetically engineered plants and certain microorganisms. USDA's regulatory jurisdiction includes crops that are genetically modified to be herbicide-resistant.
- The Environmental Protection Agency (EPA) regulates pesticides, including genetically engineered pesticides, under two laws:

1. The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) provides the legal requirements for EPA's registration process for all pesticides. With regard to biotechnology, EPA's jurisdiction under FIFRA covers regulation of the new substance and DNA in the plant when it is pesticidal in nature. For example, the substance produced by a plant that has been genetically modified to resist disease comes under FIFRA authority, whereas the substance produced by a plant that has been modified to resist drought does not.
2. Federal Food, Drug, and Cosmetics Act (FFDCA), as amended by the Food Quality Protection Act (FQPA). FFDCA requires EPA to set tolerances, or exemptions from tolerances, for the allowable residues of pesticides that are applied to food and animal feed.

## Regulatory Context of EPA's Biotechnology Enforcement

Before a pesticide can be marketed and used in the United States, FIFRA requires that the EPA evaluate the proposed pesticide thoroughly to ensure that the pesticide will not pose unreasonable risks of harm to human health or the environment. In making regulatory decisions, EPA evaluates the risks of pesticide use and balances these risks with the benefits derived from pesticide use. Pesticides that pass EPA's evaluation are granted a license or "registration" that permits their sale and use, according to the requirements set by EPA to protect human health and the environment. These requirements are generally codified through product labeling or through rulemaking and set the conditions under which the pesticide can legally be used and introduced into the environment. Compliance assessment and enforcement complete the regulatory framework by measuring the implementation of these risk managements strategies in the real world, and responding to failure as warranted.

## Pesticide Compliance Monitoring and Regulatory Enforcement

EPA's Compliance Monitoring program assesses compliance by the regulated community with environmental laws and regulations through inspections, field monitoring, and other investigations. Compliance monitoring consists of a wide range of activities:

- **Surveillance**: preinspection activity to obtain site information prior to actually entering a facility.
- **Inspections**: (on site) may include record reviews, observations, sampling, interviews, etc.
- **Investigations**: more comprehensive than inspections; may be warranted when inspection suggests the potential for serious, widespread, and/or continuing civil or criminal violations.
- **Record reviews**: may be conducted at site combined with fieldwork. Records may be derived from routine self-monitoring requirements, inspection reports, citizen/employee tips, or remote sensing.
- **Remediation compliance monitoring** as required by regulation, permit, order, or settlement ensuring timely submissions, review of submittals for adequacy, and oversight of remedial activities.

In the Pesticide Program, EPA works closely with its regulatory partners in monitoring compliance. States and tribes do most compliance monitoring activities within their jurisdictions, and FIFRA dictates that States have primary authority for compliance monitoring and enforcement related to **use** of pesticides in violation of the labeling requirements. The lead agency with primary responsibility for pesticides differs from state to state. Usually, it is a state's department of agriculture, but it may be a state's environmental agency or other agency. EPA's role in compliance monitoring includes the following:

- Collection and analysis of compliance and enforcement data;
- Responding to citizen complaints (referrals to lead agencies);
- Developing policy and legal guidance when questions arise as to the interpretation of federal environmental laws, regulations, and policies;
- Management and oversight of compliance monitoring enforcement grants to states and tribes;
- Technical assistance to states, tribal, and local governments; and
- Conducting or collaborating on inspections/investigations where state/tribal authority does not exist or when partners ask for assistance, and/or for national and regional priorities.

EPA's civil enforcement program is designed to conduct investigations and bring cases to address the most significant violations. Civil enforcement includes EPA administrative actions and judicial cases referred to the Department of Justice. EPA works closely with states to implement federal programs, as well as with tribes and federal agencies. EPA also provides information on civil enforcement related to enforcement programs and federal facilities enforcement.

Key concepts that provide a foundation for EPA's civil enforcement program include the following:

- Deterring violations by recovering economic benefit.
- Encouraging voluntary self-disclosure and correction.
- Measuring environmental results.
- Supplemental environmental projects.

## Plant-Incorporated Protectant (PIP) Rules

Because PIPs raise certain novel regulatory circumstances for the agency, EPA issued new rules in August 2001, commonly referred to as the PIP rules, that clarify the relationship between plants and plant-incorporated protectants and their regulatory status under FIFRA. In these rules, the agency has determined that, in regulating plant-incorporated protectants, the new protein and its genetic material are regulated by EPA; the plant itself is not regulated by EPA.

Because a PIP differs from a chemical pesticide in that it is one element of a biological system, as differentiated from an entire chemical constituent, some FIFRA regulatory terms require interpretation and clarification to establish compliance targets. For instance, chemical pesticide "production" occurs in a facility with that designated use. PIP production could be considered to be occurring as the result of each planted seed (which would be impracticable), or in the facility where seed generation occurs. Chemical pesticide "use" occurs where an application is made close to the target pest, at the field level, but PIP-seed introduction at the field level is not considered pesticide "use."

PIP compliance goals and enforcement activities are most easily understood in the context of the subcategories that are associated with EPA's specific authorities under FIFRA: regulation of experimental use; regulation of production and distribution; and regulation of commercially registered products.

### *Experimental Use*

FIFRA requires an experimental use permit (EUP) for experimental releases of pesticide before product registration on 10 or more acres. The EUP is received through application to the EPA, and the permit serves as an enforceable document; therefore, terms and conditions therein are the basis for compliance oversight and assessment. States have primacy for EUP compliance oversight and enforcement, although CBI-protected location information can be an impediment to state oversight. To date, the EPA has not issued specific guidance to regulatory partners about PIP EUP compliance, although state partner agencies have participated in PIP EUP inspections conducted by EPA.

During 2002, EPA Region 9 conducted PIP EUP inspections in Hawaii that resulted in two enforcement cases based on inspections at Dow AgroSciences and Pioneer's research fields on Molokai and Kauai. According to the complaints, the EPA inspector found the following:

- Dow AgroSciences did not have an appropriate tree buffer around its experimental cornfield and failed to use hybrid corn varieties as a buffer crop, both of which were required to ensure pollen containment;
- Pioneer Hi-Bred planted its experimental corn in an unapproved location, which was within 1,260 feet of other Pioneer seed production corn.

Although Dow and Pioneer neither admitted nor denied any wrongdoing, both companies settled the complaints with the agency and agreed to pay penalties to resolve the enforcement actions. In addition to paying a monetary penalty, Pioneer Hi-Bred was required to perform additional crop testing to determine whether any genetic material from the experimental plants were transferred to unmodified corn grown by Pioneer Hi-Bred in the adjacent fields.

In addition to addressing a specific risk concern, these and subsequent inspections helped to illuminate some areas of regulatory ambiguity in the PIP EUP program. The EPA is in the process of developing a public workshop to work with stakeholders to address these concerns.

### *Production and Distribution*

PIP production and distribution are regulated through Section 7 of FIFRA, which sets forth requirements about production and its reporting. Regulatory terms germane to FIFRA Section 7 require further clarification, and consequently compliance oversight and enforcement have not been active in this area.

### *Commercially Registered Products*

As an element of the risk assessment for PIPs, EPA closely evaluates the potential for pest resistance to a *Bacillus thuringiensis* (Bt) PIP. Insect resistance could affect the long-term viability of the PIP itself and also that of related conventional biopesticides such as microbial Bt sprays. The strategy of the program focuses on the level of the PIP produced and the planting of refuges (areas set within or close to a field of the genetically modified crop where unmodified versions of the same crops are planted).

The refuge requirements are codified in the legal agreement between the agency and the PIP registrant. In turn, the registrant establishes contractual agreements with their growers to ensure that these refuge requirements will be met. From a compliance oversight perspective, this is a novel approach, because it relies on contractual agreements outside of the Agency domain, and at this time, the Agency does not play a role at the level of field oversight. The compliance oversight mechanism has been carefully developed and negotiated between the agency and the consortium of relevant registrants, and involves contracted third party certifiers.

## Resources

U.S. EPA Plant Incorporated Protectants Web site includes list of currently registered products, rules, and policy documents and fact sheets. http://www.epa.gov/pesticides/biopesticides/pips/index.htm.

# Genetic Purity and Risk Management

*Dennis Thompson*

The United States accounts for the production of more than two-thirds of all biotechnology crops globally. In 2003, U.S. growers reportedly planted 81 and 40% of their respective soybean and corn acres to genetically modified (GM) crops (Pew Initiative, 2003). With this proliferation of the planting of GM crops, some stakeholders have begun to question the genetic purity of seed inputs. Others have expressed concern that the adventitious presence of GM material in commodity grains may weaken the U.S. position as a world supplier of corn and soybean. Managing perceived risks associated with the genetic purity of seed has become an issue.

Colleague Doug Miller and I presented "Gaining Perspective on Biotechnology-Driven Seed Issues" at this conference in 2002. A major focus of the presentation was to explain the core concepts embodied in the two officially recognized seed certification systems used in the United States, both of which are based upon varietal rather than genetic purity (Thompson and Miller, 2002). Stakeholder interest has since shifted toward genetic purity and away from certification issues.

There are many stakeholders who share an interest in the genetic seed purity issue. A few key groups include 1) technology developers, 2) seed companies, 3) growers, 4) grain originators, 5) grain merchandisers, 6) processors, 7) manufacturers, and 8) consumers. The perspectives of stakeholder groups vary. Each group has its own point of view. For some, the belief system is based upon mistrust of the private sector and even of science itself (CropLife Asia, 2003).

The term "genetic purity" generally refers to the freedom from the adventitious presence of undesired genetically modified seed. When non-GM seed is preferred, the presence of any detectable GM material is undesirable. When a given GM trait(s) is desired in seed, the unintended presence of other GM traits(s) is undesirable.

Granted, the seed is a primary input in the U.S. grain system. However, many factors other than seed purity can lead to point of sale rejections of grain for failure to meet genetic criteria established in producer contracts. Such contracts generally offer premiums above commodity grain prices. The U.S. commodity grain production and transportation systems are fraught with opportunities for the unintended comingling of grain. Opportunities for genetic contamination of grain are numerous and thus elevator rejections occur. Contract premiums may be forfeited. Seed purity is only one of many potential factors.

Stakeholder planning horizons differ. Some focus upon short-term issues, e.g., grain rejections, lost premiums, and seed sales. Others focus upon long-term issues, e.g., the reputation of the United States as a supplier of grain or the industry capacity to develop and release high-quality seed products to meet growing demands over time.

Several additional confounding factors surround the issue of seed and grain genetic purity: 1) inherent differences exist between crops, 2) vagaries of science, and 3) matters of practicality.

Managing, monitoring, and evaluating the genetic purity of a cross-pollinated crop (e.g., corn) is considerably more challenging than for a self-pollinated crop (e.g., soybean and wheat) due to pollen flow. In addition, due to a combination of biology and economics, some crops have had multiple GM traits introduced (e.g., corn), whereas other crops have fewer (e.g., soybean).

Science, although precise in some respects, is imprecise in others. Testing results are predicated upon the random sampling of large populations. Sampling error can be minimized but not eliminated. Results are obtained at a specified level of confidence, which ranges somewhere below 100%. Detection levels for GM traits are affected by the underlying science of the test used in addition to the size of the sample being tested. Finite answers are unattainable. Risk is present.

Practicality. GM trait determination requires sophisticated methodology, is time-consuming, and is generally considered to be expensive. A registered genetic technologist or scientist using appropriate technologies can best perform the work in a controlled laboratory setting. Grain delivery points cannot justify the time, money, and level of expertise to perform appropriate on-site tests. Grain facilities must make decisions rapidly about whether to accept or reject grain.

Risk management strategies and tolerance levels differ among stakeholders. Some stakeholders prefer additional information about the genetic purity of seed to enhance their ability to determine an appropriate level of business risk associated with producing or using grain for certain purposes. Some may seek a means to transfer responsibility for grain purity to others. Others may be reluctant to share information about genetic purity for fear it may be used unfairly against them.

Some stakeholders believe that adequate information about seed genetic purity is currently available. Others perceive that adequate information about seed genetic purity is lacking. These differences in perspective will likely fuel numerous future discussions.

## References

CropLife Asia. September 2003. The real meaning of IPM agVIEW ASIA (Issue 8) [On-line]. Available at http://www.croplife.asia.org.

Pew Initiative on Food and Biotechnology. October 2003. Genetically modified crops in the United States (factsheet 2). Washington, DC.

Thompson DR and Miller DE (2002). Gaining perspective on biotechnology-driven seed issues, in *Illinois Crop Protection Technology Conference*, p 41. University of Illinois, Urbana.

# Fulfilling IP Contracts for Grains and Oilseeds

*Lynn Clarkson*

Some buyers want grains and oilseeds that represent values not respected by commodity markets. Such values may be found in process features such as water absorption rates, product traits (color or taste), market access requirements (organic certification, food security, and traceability), or market-influencing origination stories. To enjoy perceived market advantages, buyers use production and supply contracts to provide necessary incentives to those in their supply chain. The nature of these contracts varies greatly. But, in all cases, buyers use contracts with producers or with supply coordinators and intermediate processors to secure what they want when they want it and to avoid what they do not want. These closed systems are becoming more common and more important to U.S. agriculture.

In fulfilling such contracts, the primary challenge is to identify the client followed closely by learning as much as possible about what the client wants and why he or she wants it. For the sake of explanation, let's take a reasonably extreme example. Assume that our client, George, has clearly explained that he wants 12,000 metric tons (about 480,000 bu) of a particular variety of red corn for a new cereal. It must be certified organic under International Federation of Organic Ag Movements (IFOAM) rules as well as the National Organic Program (NOP). It must be verified non-genetically modified organism (GMO) with a tolerance of only 0.1% by using an approved polymerase chain reaction (PCR) testing laboratory. George wants it to be 99% pure as to variety, delivered throughout a year in scattered shipments commencing November 1, 2004. He expects protein to be better than 10%, physical quality to exceed US#1 grade standards. The contract permits no more than 0.1% foreign material or damage. George has agreed to pay you enough to pay the farmer 14¢/lb ($7.84/bu). The hybrid he wants typically yields 80 bu/acre.

Can you fulfill that contract? It depends. Without stifling your creativity, there are helpful protocols that you can follow. Success depends on a chain of players starting with you and your own organization's ability to plan and execute with discipline. In this brief presentation, I address key planning steps as well as the particular challenges involving seed supplier, farmer, conditioner and quality control throughout the process. Done well, you might find the elusive grail—a happy client, one that says "Thank you." Along the way, I think you will develop an appreciation for good third party certifiers.

# Soybean Aphid in the Midwest: Looking Toward a Dynamic Threshold—Emerging Recommendations, Lingering Questions

*Eileen M. Cullen, John Gaska, Scott Myers, Bryan Jensen, Craig Grau, and Roger Borges*

Last year, at the 2003 Illinois Crop Protection Technology Conference, Ken Ostlie (University of Minnesota) appraised the soybean aphid situation under the apt title "Gathering Storm or Dissipating Threat? Status, Prognosis, and Management of the Soybean Aphid". As has been widely reported, the soybean aphid, *Aphis glycines* Matsumura, was first observed in the Midwest in July 2000 (Gallepp, 2003). Given variable population levels of this emergent pest since its discovery, researchers, extension agents, growers, and crop consultants have just a couple of years of soybean yield response, economic injury level, and insecticide efficacy data on which to base treatment decisions. During summer 2003, soybean aphid was found at record high densities in most of the soybean-growing areas in the central and upper Midwest. Heaviest infestations were observed in Wisconsin, Iowa, Illinois, Michigan, and Minnesota with millions of acres receiving between one and two applications of pyrethroid and/or organophosphate insecticide throughout the region. Here we are, January 2004, still reeling (and interpreting data) from the effect of that storm Ken Ostlie alluded to at last year's conference.

The objectives of this symposium presentation are to 1) discuss the current status of chemical control tactics (foliar contact activity materials and insecticidal seed treatments) for soybean aphid; 2) present collective results and observations from University of Wisconsin foliar insecticide efficacy, seed treatment, spray timing and varietal trials; and 3) continue the dialogue on soybean aphid treatment thresholds, with reference to the potential for dynamic threshold development seemingly inherent in this crop–pest association.

## Status of Chemical Control Tactics for Soybean Aphid (2003)

Soybean aphid causes both direct and indirect effects on soybean that can lead to yield loss and reduced seed quality. Direct feeding damage results in subsequent plant stress, stunting, and yield loss. Indirectly, soybean aphids have been found to reduce photosynthetic rate in soybean (Macedo et al., 2003). Winged soybean aphid morphs occur early in the growing season as females migrate from the primary (overwintering) host, buckthorn (*Rhamnus* spp.), to the secondary host, soybean (*Glycine max*), for the asexual development phase (Zhang and Zhong, 1982). A summer wing morph develops later in the growing season as females respond to crowding and decreased host quality by dispersal flight to uncolonized plants and fields (Steffey, 2003). It is the winged soybean aphids that are capable of transmitting soybean viruses as they probe and feed between infected and uninfected plants during movement between fields. Because soybean viruses can be transmitted rapidly by winged aphids, there are no thresholds to control this indirect damage (yield loss and seed mottling effects) caused by soybean aphid (Grau, 2003).

Soybean aphid chemical control tactics, and ultimately overall management strategies, should take

into account both the direct and indirect effects of soybean aphid on the crop. As in the previous 3 years since soybean aphid emerged in the Midwest, the primary control tactic to manage direct effects of soybean aphid feeding during the 2003 growing season was to apply a pyrethroid foliar insecticide by ground or air. Examples of pyrethroids include Asana XL (active ingredient esfenvalerate); Warrior (lambda-cyhalothrin); and Mustang Max (zeta-cypermethrin). The organophosphates dimethoate and Lorsban 4E (chlorpyrifos), and the carbamate Furadan 4F (carbofuran) also are registered for soybean aphid.

Other than winged morphs, aphids are relatively sedentary on the plant as they feed with piercing-sucking mouthparts. Thus, they do not move quickly enough through the canopy after a foliar pyrethroid application (nor does their feeding mechanism permit) to encounter additional treated plant surfaces or ingest active ingredient. For pesticides that work primarily by contact activity, it is critical that a lethal dose be delivered to the site at which the aphid is located (Cullen et al., 2001). Contact activity materials are relied upon to manage direct soybean aphid effects by reducing pest population pressure and plant stress quickly. In the long term, contact activity materials are expected to be most effective if used in an integrated pest management (IPM) program for which soybean aphid economic thresholds, optimal spray timing, and delivery methods have been determined.

Insecticidal seed treatments applied to soybean before they are bagged and sold are another developing option for soybean aphid. This technology, already registered in field corn, has seen limited registration on soybean. Gaucho (nicotinoid active ingredient imidacloprid) was registered under a Section 18 emergency exemption in Wisconsin beginning March 28, 2003, for control of bean pod mottle virus transmitted by the bean leaf beetle. This exemption registration expired June 1, 2003, and nicotinoid seed treatments continue to be in the preregistration, development phase as of the 2003 soybean harvest at the time this article was written. Nicotinoid insecticides have systemic activity within the treated plant. When applied as a seed treatment, active ingredient is taken up into the germinating seed through developing root, stem, and leaf tissues. Three nicotinoid insecticidal seed treatment active ingredients currently in the trial phase on soybean are Cruiser (active ingredient thiamethoxam), Gaucho (imidacloprid), and Poncho (clothianidin). As in the corn seed treatment market, Cruiser is manufactured by Syngenta, whereas Gaucho and Poncho are manufactured by Bayer CropScience with Gustafson LLC.

Unlike the broad-spectrum contact activity materials discussed previously, nicotinoid seed treatments have selective activity against piercing-sucking insects with negligible effects on nontarget organisms (e.g., natural enemies important in regulating aphid population growth). This systemic mode of action means that soybean aphids ingest active ingredient during feeding, thus preventing further direct feeding stress and reducing virus transmission by protecting plants from potential vectors as winged aphids arrive in a field.

Nicotinoid seed treatments typically have activity within a growing plant for at least 4 to 6 weeks after germination, sometimes longer, depending on active ingredient, seed treatment rate, crop, and target pest susceptibility. Thus, nicotinoid seed treatments are expected to be best suited for early- to mid-season protection against the direct and indirect effects of soybean aphid. Soybean is treated on a grams of active ingredient per 100 kg of seed basis. For example, Poncho 62.5 and Cruiser 30 would equate to 62.5 g clothianidin/100 kg seed and 30 g thiamethoxam/100 kg seed, respectively. The situation is different for corn seed treatment where field corn seed can range in size (e.g., 1,400–2,800 seeds/lb) and seed is sold on a seed count basis. To obtain the same active ingredient rate per seedling, nicotinoid seed treatments are made to field corn on a milligrams of active ingredient per kernel basis.

## 2003 Insecticide Efficacy Trials – A Sampling of Wisconsin Data

Foliar insecticides and insecticidal seed treatments were evaluated in three different trials for efficacy against soybean aphid at the Arlington Agricultural Research Station, Arlington, WI. The foliar insecticide trial, designed to evaluate residual activity as measured by aphid counts at successive intervals post-treatment, included nine treatments (seven pyrethroids and two organophosphates) in a completely randomized block design (CRBD) with four replicates per treatment. Post-treatment aphid counts (Table 1) were significantly different ($P < 0.05$) by treatment at three post treatment sampling dates, suggestive of varying residual activity between treatments.

Two nicotinoid seed treatment trials, with aphid counts and yield data as response variables, were designed to investigate how long seed treatment systemic activity extends into the growing season. With the exception of cultivar (trial 1, NK S19-V2; trial 2, NK S240K4) and treatment variables, experimental design was the same for both seed treatment trials. Trial 1 included five treatments: Poncho 62.5 (clothianidin), Poncho 125, Gaucho 62.5 (imidacloprid), Cruiser 62.5 (thiamethoxam), and an

**Table 1 Soybean aphid foliar insecticide trial. Mean aphids/plant 4 days, 1 week, and 2 weeks post-treatment[1]. Treated July 31 at R2 (>500 aphids/plant).**

| Treatment | 4 days | 1 week | 2 weeks |
|---|---|---|---|
| Untreated | 996.5 a | 1518.8 a | 1823.5 a |
| Warrior 1CS 3.84 oz. | 26.3 f | 22.2 e | 72.6 e |
| dimethoate 1 pt. | 36.2 e | 45.5 d | 147.0 c |
| Baythroid 2.8 oz.* | 181.5 d | 344.5 b | 476.0 b |
| Mustang Max 4.0 oz. | 203.2 d | 200.3 c | 307.8 c |
| Mustang Max + NIS | 353.9 b | 437.1 b | 440.6 b |
| Capture 2.56 oz.* | 1.1 g | 9.6 f | 50.8 f |
| Asana 6.4 oz. | 330.4 b | 346.5 b | 349.3 b |
| Asana 9.6 oz. | 204.6 c | 368.3 b | 168.9 c |
| Lorsban 4E 2.0 pt. | 0.5 g | 15.3 e | 91.9 d |

[1] Mean yields (bu/acre) within a column followed by a different letter are significantly different at $\alpha = 0.05$ (Fisher's exact test).

* Baythroid (See supplemental label for soybean aphid); Capture not currently registered for soybean aphid.

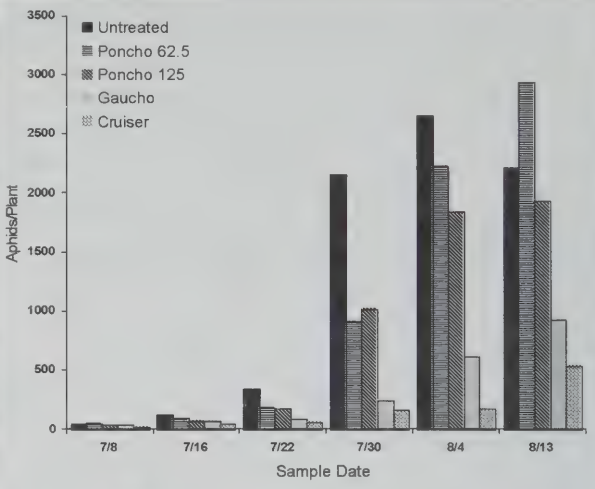



**Figure 1 Nicotinoid seed treatment on soybean (soybean aphid trial 1). Mean aphids per plant across sampling dates.[1] University of Wisconsin, 2003.**

[1] Mean aphids/plant significantly different across sample dates at a = 0.05 (Fisher's exact test):

| | |
|---|---|
| July 8 | $P < 0.0001$; $F = 8.38$; df = 4 |
| July 16 | $P < 0.0001$; $F = 17.8$; df = 4 |
| July 22 | $P < 0.0001$; $F = 28.96$; df = 4 |
| July 30 | $P < 0.0001$; $F = 69.42$; df = 4 |
| August 4 | $P < 0.0001$; $F = 54.74$; df = 4 |
| August 13 | $P < 0.0001$, $F = 52.05$; df = 4 |

untreated check. Trial 2 included four treatments: Cruiser 30, Cruiser 50, Gaucho 62.5, and an untreated check. Plots were seeded in 30-inch rows in a CRBD with four replicates per treatment on June 9, 2003. Each treatment replicate was 10 ft (4 rows) in width by 25 ft in length. To assess early through mid-season systemic activity of the seed treatments, aphid counts were taken from each plot beginning with initial aphid colonization in the plots (July 8) and continuing at weekly intervals through August 13, when untreated check plot populations began to decline. Whole plant aphid counts were taken on 10 plants per replicate, randomly selected from the middle two rows of each plot, and mean aphids per plant was determined for each plot across sampling dates. Yield data were recorded at harvest on 16 October.

Figure 1 illustrates a significant difference ($P < 0.05$) in mean aphids per plant between treatments at each sample date for trial 1. The same pattern was observed in trial 2 (Fig. 2). As measured by mean aphids per plant, Cruiser (thiamethoxam) at the 50 and 62.5 g ai/100 kg seed rates, and Gaucho (imidacloprid) at the 62.5 g ai/100 kg seed rate seemed to have the longest systemic activity into the growing season at approximately 65 days between seeding and the final aphid count on 13 August when plants were in the R3 stage. Mean separation results for yields in each trial reflected this same pattern with the highest yields corresponding to treatments with the lowest aphid counts on 13 August (Tables 2 and 3).

## Looking toward a Dynamic Soybean Aphid Threshold

Little is known about interactions between soybean developmental stage and susceptibility and tolerance to soybean aphid injury in the Midwest. Soybean aphid is native to east Asia and China in particular, where a substantial body of literature on soybean aphid (e.g., sampling, thresholds, cultivar resistance, biological control) exists [Soybean aphid literature translation project, http://www.ksu.edu/issa/aphids/reporthtml/projectii.html]. Aphid density is dynamic in the field, aphids multiply as plants grow, and infestation can be enduring and continuous. The ratio of plant size to aphid density that the plant can tolerate is vital to understanding aphid damage (Dai and Fan, 1991). Chinese researchers successfully identified resistance of soybean to soybean aphid and obtained a batch of source breeding material (cited in He et al., 1995). On the basis of this work, researchers in east Asia have continued to document varying

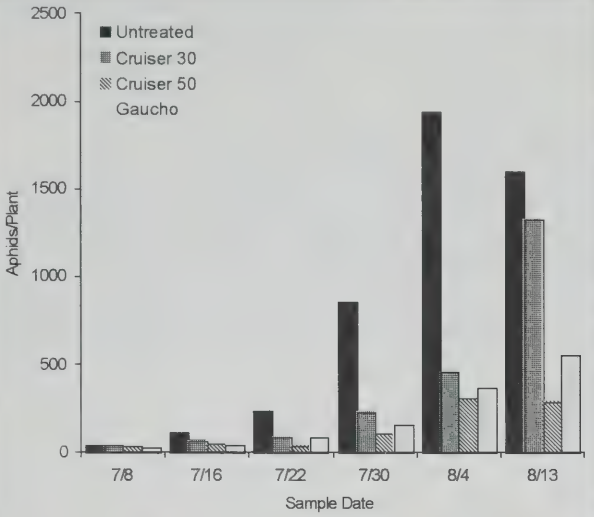



**Figure 2. Nicotinoid seed treatment on soybean (soybean aphid trial 2). Mean aphids per plant across sampling dates.[1] University of Wisconsin, 2003.**

[1] Mean aphids/plant significantly different across sample dates at a=0.05 (Fisher's exact test):

| | |
|---|---|
| July 8 | $P = 0.0122$; $F = 3.00$; df = 5 |
| July 16 | $P < 0.0001$; $F = 18.66$; df = 5 |
| July 22 | $P < 0.0001$; $F = 30.54$; df = 5 |
| July 30 | $P < 0.0001$; $F = 41.77$; df = 5 |
| August 4 | $P < 0.0001$; $F = 446.93$; df = 5 |
| August 13 | $P < 0.0001$, $F = 313.33$; df = 5 |

**Table 2. Nicotinoid seed treatment on soybean (soybean aphid trial 1). Mean yield (bu/acre) by treatment.[1] ($P = 0.1151$, $F = 2.33$, df = 4). University of Wisconsin, 2003.**

| Treatment | Yield (bu/A) |
|---|---|
| Untreated | 38.1 b |
| Poncho 62.5 | 42.2 ab |
| Poncho 125 | 44.3 ab |
| Gaucho | 43.2 ab |
| Cruiser | 52.8 a |

[1] Mean yields (bu/acre) followed by a different letter are significantly different at a = 0.05 (Fisher's exact test).

**Table 3. Nicotinoid seed treatment on soybean (soybean aphid trial 2). Mean yield (bu/acre) by treatment.[1] ($P = 0.1151$, $F = 2.33$, df = 4). University of Wisconsin, 2003**

| Treatment | Yield (bu/A) |
|---|---|
| Untreated | 38.1 c |
| Cruiser 30 | 43.6 bc |
| Cruiser 50 | 49.7 ab |
| Gaucho | 41.3 bc |

[1] Mean yield (bu/acre) followed by a different letter are significantly different by at a = 0.05 (Fisher's exact test).

levels of potential resistance or tolerance among soybean cultivars to soybean aphid (Chung et al., 1980).

Collective University of Wisconsin results and observations from spray timing and varietal trials over the past couple of years are reviewed. Foliar insecticide and seed treatment efficacy trials such as those presented herein are important first steps in developing uniform treatment recommendations for soybean aphid throughout the Midwest. As discussed previously, in the long term, chemical control tactics (broad spectrum or selective) will be most effective if used in an IPM program for which soybean aphid economic thresholds, optimal spray timing, and delivery methods have been determined. We are not there yet, but the idea of a dynamic threshold has surfaced in discussions and observations with some growers and consultants and researchers, and can be traced back to the Chinese literature on soybean aphid in its native territory.

## References

Chung KH, Kwon SH, and Lee YI. 1980. Studies on the density of soybean aphids in different cultivars, planting dates and spacing. *Journal of the Korean Society for Crop Science* 25: 35–40. Translation: http://www.ksu.edu/issa/aphids/reporthtml/citationspage3.html.

Cullen E, Zalom F, Steinke W, and Hummel N. 2001. High-volume applications to improve canopy penetration and efficacy of reduced risk insecticides in processing tomatoes. *Acta Horticulturae* No. 542, in Proceedings of the 7th International Symposium on the Processing Tomato (Hartz TK ed), pp 31–37. ISHS, Belgium.

Dai ZL and Fan J. 1991. Effects of aphid population dynamics and damage period on soybean yield. *Journal of Shenyang Agricultural University* 22: 135–139. Web translation available at http://www.ksu.edu/issa/aphids/reporthtml/citationspage4.html.

Gallepp G. 2003. Uninvited, but here to stay. College of Agricultural and Life Sciences Science Report 2002–2003. University of Wisconsin-Madison. http://www.cals.wisc.edu/sciencereport/02SRstories/Uninvited.html.

Grau C. 2003. Insect-soybean-virus complex in Wisconsin. http://www.plantpath.wisc.edu/soyhealth/virus.htm.

He FG, Liu XD, Yan FY, and Yan QW. 1995. Study on soybean aphid resistance. *Liaoning Agricultural Science* 4: 30 Yan 34. Web translation available at http://www.ksu.edu/issa/aphids/reporthtml/citationspage9.html.

Macedo TB, Bastos CS, Higley LG, Ostlie KR, and Madhavan S. 2003. Photosynthetic responses of soybean to soybean aphid (Homoptera: Aphididae) injury. *Journal of Economic Entomology* 96: 188–193.

Soybean aphid literature translation project, phase II. 2002–2003. http://www.ksu.edu/issa/aphids/reporthtml/projectii.html

Steffey K. 2003. Numbers of soybean aphids keep increasing. University of Illinois Extension Pest Management and Crop Development Bulletin, July 10, 2003. http://www.ag.uiuc.edu/cespubs/pest/articles/200316b.html.

Zhang GX and Zhong TS. 1982. Experimental studies on some aphid life-cycle patterns. Sinozoologia 2: 7–17.

# Weed Management Challenges from 2003

*Aaron G. Hager*

The 2003 growing season had its share of weed management challenges, but overall there did not seem to be as many momentous issues as in previous years. The following describes some of the more significant weed management challenges from 2003.

## Herbicide-resistant Weeds

Beginning during the latter half of the 1980s, herbicide resistance was becoming more common in many states and around the world. However, by 1993 researchers in Illinois had documented herbicide resistance in only three weed species biotypes, and resistance was to only one herbicide family. A decade later, the list of herbicide-resistant weed biotypes in Illinois had grown to include 10 species, and resistance had spread to include four herbicide families (Table 1). The most recent addition to the list of herbicide-resistant biotypes is a waterhemp population with resistance to three herbicide families (triazine, acetolactate synthase [ALS] inhibitors, protoporphyrinogen oxidase [PPO] inhibitors). Researchers at the University of Illinois are continuing to examine this biotype to determine the mechanisms responsible for its herbicide resistance characteristics.

The majority of herbicide-resistant weed biotypes in Illinois are broadleaf species, but concern currently exists that there may be an increase in grass species (giant foxtail, in particular) demonstrating resistance to ALS-inhibiting herbicides. This type of resistance has been documented previously in Illinois (Table 1); however, recently we have received several requests to screen giant foxtail and shattercane biotypes for resistance to ALS inhibitors. The increasing occurrence of herbicide-resistant weed biotypes in Illinois continues to reduce the effectiveness of many herbicide options.

## Insects in Weeds

Similar to 2002, insect feeding within the stem tissue of various weed species was very noticeable in some areas of Illinois and may have contributed to poor weed control after the application of a postemergence herbicide. Weed species that "harbored" these insects included waterhemp, giant ragweed, horseweed/marestail, annual smartweed species, common ragweed, and common lambsquarters. To date, researchers have identified insects in the orders Lepidoptera (*Papaipema nebris*, *Ostrinia nubilalis*, *Epiblema* spp.) and Coleoptera (*Rhodibaenus tredecimpunctatus*, *Lixus* spp., *Dectus* spp., *Hippopsis lemniscata*) present in these weed species as either larvae or adults. Research is currently underway to examine many important questions related to this phenomenon, such as how extensively herbicide translocation is reduced by insect tunneling and at what stage of plant growth do these insect species begin their association with the weeds.

## Late-season Observations

During late September and early October 2003, we traveled across a large area of Illinois collecting

samples of waterhemp from soybean fields. These travels also provided an opportunity to survey the weed species present at the end of the growing season. As expected, waterhemp was the predominant weed species in mature soybean fields. The next most common weed species was somewhat region specific. Giant ragweed was very common in northern and northwestern Illinois, whereas common lambsquarters was frequently noted in other areas. One observation that was somewhat surprising was the number of fields with mature horseweed/marestail. From our anecdotal observations, we have no idea whether these plants may have simply survived an early-season burndown herbicide application, emerged later during the spring, or survived a postemergence herbicide application. Regardless, we should remain watchful towards this weed species because glyphosate-resistant biotypes of horseweed/marestail have been discovered in the border states of Indiana and Kentucky.

**TABLE 1 Herbicide-resistant weed species in Illinois.**

| Common name | Scientific name | Resistant to herbicide family(ies) |
|---|---|---|
| Common lambsquarters[1] | *Chenopodium album* | Triazine |
| Smooth pigweed[1] | *Amaranthus hybridus* | Triazine, ALS inhibitors |
| Kochia[1] | *Kochia scoparia* | Triazine, ALS inhibitors |
| Eastern black nightshade | *Solanum ptycanthum* | ALS inhibitors |
| Giant ragweed | *Ambrosia trifida* | ALS inhibitors |
| Common ragweed | *Ambrosia artemisiifolia* | ALS inhibitors |
| Common cocklebur | *Xanthium strumarium* | ALS inhibitors |
| Common waterhemp | *Amaranthus rudis* | Triazine, ALS inhibitors, PPO inhibitors |
| Shattercane | *Sorghum bicolor* | ALS inhibitors |
| Giant foxtail | *Setaria faberi* | ALS inhibitors, ACCase inhibitors |

[1]Herbicide-resistant biotypes identified in Illinois by 1993.

## Summary

Collectively, the scenarios described herein are not necessarily unique to the 2003 growing season. Rather, they provide evidence that obtaining effective weed management continues to be challenged by changes in the weed spectrum. New challenges will undoubtedly surface in the near future, and we need to be continually vigilant for them and respond accordingly.

# Illinois Crop Disease Issues in 2003

*Dean Malvick*

It is difficult to generalize and summarize the crop disease problems throughout Illinois in 2003. Although several disease problems were significant over large areas, others were important only in small areas but still had major impacts on some producers. The growing season started with a cool and wet May in parts of Illinois, followed by a cool and dry June over large areas, a cool and wet July over large areas, and then a warm and dry August.

Overall, corn diseases were a minor problem, with exceptions in some areas, and yields were very good in much of the state. Due in part to the cool weather in June and July, common rust was a problem, primarily in northern and central parts of Illinois. Gray leaf spot was prevalent, as usual, but generally did not cause much yield loss. Northern corn leaf blight was significant in some seed production fields, and crazy top was reported from some areas that had large amounts of rain early in the season. Stalk rots were a concern at the end of the season in many areas, but they failed to become a major problem. In addition, *Diplodia* (*Stenocarpella*) ear rot was a problem in some areas in southern Illinois where rain fell at flowering, and Fusarium ear rot and contamination of grain with fumonisins occurred in scattered areas.

Although disease had minor impacts overall on corn production, disease seemed to have a much greater impact on soybean production. Many diseases were reported on soybean, including seed and seedling diseases, various root rots, Phytophthora rot, sudden death syndrome, brown stem rot, and soybean cyst nematode (SCN). The abnormally cool and wet July prompted scattered outbreaks of white mold in northern Illinois that hadn't seen much of this disease for several years. Frogeye leaf spot was reported for the first time in northwestern Illinois. Stem canker was a significant problem late in the season in areas of the northern half of Illinois, and work is ongoing to understand whether this problem was primarily due to the northern or southern type of stem canker. Although all of these diseases raised concern and reduced yields in some fields, the two disease problems that perhaps were discussed most widely were root rot, top death in mid-July, and charcoal rot in August and September. Root rot and top death were major concerns in central Illinois, and the symptoms reported seemed to be associated with heavy rains in early July. Charcoal rot was widespread late in the season due in large part to the hot and dry conditions present over much of Illinois in August, and the root rot issues in some areas also may have contributed to this problem.

Wheat in Illinois was plagued with several foliar diseases, including more stripe rust than previously reported in Illinois. But the severity of these foliar problems seemed minor compared with the impact of Fusarium head blight (head scab). The wet weather in May and into June created excellent conditions for scab development in much of southern Illinois. Although wheat yields were good in many fields in spite of the scab, much of the wheat in the southern half of Illinois had high levels of the mycotoxin deoxynivalenol (DON). The alfalfa crop fared reasonably well this year, although in some areas Aphanomyces root rot inhibited stand establishment, and leaf diseases and Verticillium wilt were reported. This report is not a complete summary of all the diseases in Illinois field crops in 2003, but it does highlight major problems. For all of these crops, additional scouting would reveal other diseases that reduce yields, stands, and crop quality.

# Issues in Crop Management

*Emerson D. Nafziger*

The 2003 growing season will be long-remembered for unusual yields. New statewide high-yield records were established in wheat and corn, and the soybean yield was the lowest since the drought of 1988. Why did crops respond the way they did, and what management lessons can we take away from this past year?

Reference is made several times in this paper to the University of Illinois Crop Sciences Variety Test results. These are available at http://vt.cropsci.uiuc.edu/.

## Wheat

The new Illinois state yield record set for wheat in 2003 was 65 bu/acre, on 810,000 acres. After a rather unremarkable fall and winter, the weather in March and April was almost perfect, with low rainfall, lots of sunshine, and cool-to-moderate temperatures. Not even excessive rainfall in May in some areas could detract much from yields, given the excellent filling weather in May and June. As is typical in Illinois, yields were higher from south to north, although acreage in central and northern Illinois is very small. The average yield of the three University of Illinois wheat variety trials in the northern half of the state was 113 bu/acre, and at DeKalb the variety trial averaged 128, with a single entry producing 152 bu/acre. The only sour note in the 2003 wheat crop in Illinois was the high levels of vomitoxin (produced by the Fusarium head scab fungus) in some areas. Ironically, this problem was made worse because infected grains developed so well and so did not get blown out of the combine.

### *Management Issues*

- Under outstanding conditions, variety choice affected yields a great deal.
- Most management inputs had minimal effects on yield. For example, spring nitrogen (N) rate did not affect yield at all in a trial at Urbana.
- Vomitoxin levels differed some among varieties, and selection might be possible.

## Corn

Corn yields in 2003 obliterated previous records: as of the October crop report, average statewide corn yield in Illinois is projected to be 169 bu/acre, 13 bu/acre higher than the previous record of 156 in 1994, and the highest Corn Belt state yield ever recorded. Planting progress for the corn crop was fairly typical, with 50% planted by about May 10 and 90% planted by May 25, with delays in southern Illinois. Stands were generally good to outstanding.

Growth and development were typical, with crop progress similar to that in 2002, but somewhat behind the 5-year average. Crop condition reports rated the corn crop highly throughout the growing season, but projected yields increased by about 10% (15 bu/acre) from the September to the October estimate, due to larger than anticipated kernel size. Although the weather was moderate for most of the

season, with adequate to excessive rainfall and relatively cool temperatures from May to July, it was warm and dry during most of August, and the late increase in kernel size was not anticipated. Grain filling rates were clearly very high during much of the grain-filling period, and rain at the end of August revived grain fill.

### *Management issues*

- With few diseases, hybrid yields were little affected by disease resistance or susceptibility, and performance of different hybrids was relatively uniform among locations. Yields were high, and so predicted performance from these trials is likely to be most applicable in high-yielding environments next season.
- Plant population responses tended to be slightly less than normal due to very large ears at low populations, but optimal populations were still high. A study at Urbana produced 199 bu/acre at 15,000 plants and 263 bu/acre at 35,000 plants, and at Monmouth the same hybrids produced about 161 bu/acre at 15,000 and 245 bu/acre at 35,000 plants/acre.
- The rotation response—corn following soybean versus corn following corn—was variable: the difference in a Monmouth trial at optimum N rates was 90 bu/acre in favor of corn following soybean, but at Urbana was only 3 bu. Although some corn clearly benefited greatly from following soybean in 2003, this benefit was less in areas with better rainfall. In the Morrow Plots, well-fertilized corn yielded 244 bu/acre in the oat–alfalfa–corn rotation, 206 in corn following soybean, and 183 in continuous corn.
- Responses to N were normal to less than normal; as we have seen before, years when the weather favors high corn yields tend to be those with high release of N from soil organic matter or previous residue. In the Morrow plots, corn without fertilizer N yielded 171 in the oat–alfalfa–hay rotation, 106 in soybean–corn, and 63 in continuous corn. In general, though, the optimal N rates were not much different than we have seen in previous years, and N rate recommendations will not change.
- A new technology—corn seed coated with temperature-sensitive polymer that only allows water through once soil temperatures are above a minimum—provided only modest (1 day or so) delays in emergence even with March plantings in Illinois and other states, and had little effect on yield. Whether such technology provides cost-effective insurance against stand loss from very early planting remains to be seen.

## Soybean

In contrast to corn and wheat, soybean yields were very disappointing in Illinois in 2003; the projected average yield is only 37 bu/acre, the lowest in 15 years. This outcome followed yields in 2002 that ranged from very good in some parts of the state to below average, especially in parts of northern Illinois.

Although soybean aphids, Japanese beetles, and a number of diseases were present in many Illinois soybean fields in 2003, it is likely that soybean yield decreases were due mostly to a very unfavorable weather pattern. The cool, wet weather in June and part of July was very good for corn and for soybean vegetative development (except where rainfall was excessive), but not for soybean root, pod, and seed development. Flowering was a week to 10 days later than usual, and by the time pod setting began in early August, dry weather set in and the crop was in trouble. In some fields, seed size was very small, with reports of seed as small as 5,000 seeds/lb, or half normal size. In other fields, were abortion thinned pod numbers, seeds were larger, but pod numbers and seeds per pod were low. One of the unusual features of the low statewide yields was the near lack of fields with high yields, anywhere in the state. This finding helps to confirm that the major problem was not insects or diseases, but rather weather that held over much of the state.

### *Management issues*

- In general, variety comparison locations with very low yields do not provide good data for predicting future performance. Thus, many variety trials in 2003 should probably carry less weight than normal.
- Early-maturing varieties, probably because they had less ability to withstand the dry weather in August, did relatively worse than usual compared with mid-season or later-maturing varieties. Using early-maturing varieties to enable earlier harvest or to spread weather risk may be a strategy that needs rethinking.
- Planting date studies generally showed fairly typical effects of planting date on yield, though sometimes earlier plantings did relatively better, perhaps because the root systems of earlier planted soybean were able to grow more, thus helping the crop gather water in August.
- Seeding rate responses were typical, with little benefit to planting more than 150,000 or so viable seeds per acre.
- Anecdotal evidence is that wider rows often produced higher yields than narrow rows in 2003. This outcome may have had to do with

high plant populations usually seen with narrow rows, and narrower rows may have used up available soil water faster, and hence suffered more during dry weather. White mold also may have contributed to this effect in northern Illinois. An inoculant study conducted at 12 locations in Illinois showed no effect of this input. With water limiting yields, plants likely could not benefit even from extra N that might have been available with inoculant. Also, N fixation takes energy (sugars), which was probably in very short supply in soybean fields in August.

## Crop Rotation

The corn:soybean yield ratio (bu:bu) over the past 10 years in Illinois has been at or slightly above 3. This relative ratio provides similar returns for the two crops, with yield advantages to both crops in rotation. In 2003, this ratio was more than 4 statewide, and for some individual producers it was above 5. Although it is true that having soybean in fields in 2002 helped 2003 corn yields to be as high as they were, a ratio of 4 to 5 is not sustainable at current prices, and many producers will address this income problem by producing more corn and less soybean. With so much of the cropped area in Illinois in a 2-year rotation of these two crops, most increase in corn acres will have to be corn that follows corn in the rotation. This management challenge is one that we will all have to address.

# Crucial Conversations . . . Tools for Talking when Stakes are High

*Ben Mueller and Anne Heinze Silvis*

*Crucial Conversations*, published in 2002, is the resource book for a training seminar that addresses the issue of how to have a discussion between two or more persons where the stakes are high, opinions vary and emotions run strong. The workshop will provide an introduction to dialogue tools to help one successfully initiate difficult and important conversations with candor and achieve desired, positive outcomes.

The following Crucial Conversations skills will be highlighted:

- Focus on what one really wants to communicate.
- Watch for silence and/or violence (in the dialogue).
- Apologize when appropriate in contrast to "fixing" a misunderstanding.
- Separate fact from "clever" stories (Victim, Villain and Helpless).
- Share your facts; tell your story.
- Ask, mirror, paraphrase then agree, build or compare.
- Document decisions and account for action.

## Resources

### *Books*

Patterson, Kerry, Joseph Grenny, Ron McMillan and Al Switzler. 2002. *Crucial Conversations Tools for Talking when the Stakes are High*. New York: McGraw-Hill Co.

### *On the Web*

http://www.communitydevelopment.uiuc.edu/conflict
Visit this site for an extensive listing of books, newsletters and journals, additional web resources, videos and an interactive self-directed learning CD entitled *Conflict: An Opportunity for Development.*

# Got Dead Stuff?

*N. Dennis Bowman, Nancy Pataky, and Jim Stedelin*

This presentation focuses on new tools that you can use to solve your plant and pest problems. Speakers representing the Illinois Department of Agriculture Animal Diagnostic Lab, the University of Illinois Plant Clinic, and University of Illinois Extension Distance Diagnostics explain new techniques and technologies that provide answers to today's crop problems. The importance of enzyme-linked immunosorbent assay (ELISA) and polymerase chain reaction (PCR) are explained. These methods enable more accurate diagnosis of pathogens, allowing growers to more accurately target pesticide applications, reducing the quantity and cost of chemicals used. A resource relatively unknown to crop consultants and producers, the Illinois Department of Agriculture (IDOA) Animal Diagnostic Lab in Centralia offers a variety of cost-competitive tests that can be of benefit to crop producers, including analysis for pesticide residues and aflatoxins. The Plant Clinic is part of a newly emerging, nationally integrated Plant Diagnostic Information System (PDIS). This network provides tools for accessing more information and specialists for help in diagnosis. The digital age also has brought some new tools to the diagnostic arena. The Internet and digital cameras are being used to get quick answers to crop problems. Find out how you can best use these new diagnostic tools at this presentation.

# Cleaning Up Your Act: Reducing Pesticide Cross-Contamination

*Michael Helms and Dave Fredrickson*

Cross-contamination due to improperly or inadequately cleaning application equipment or due to contamination from rinsate disposal can lead to crop loss, environmental pollution, fines, lawsuits, loss of applicator certification, and loss of income. Pesticide labels often have information on how to clean equipment, but frequently the information is vague or lacking. Cross-contamination from sprayers can be reduced by using sprayer components made from pesticide-resistant materials, removing enough liquid from the sprayer during cleaning, using dedicated sprayers, adopting engineering controls to clean sprayers or reduce the amount of contamination, or using special cleansers.

Cross-contamination also can occur due to repackaging activities. Cases have been investigated in several midwestern states of crop damage that seemed to be from pesticides. What has been found is that mini-bilk containers are being used for more than one active ingredient or have not been totally emptied between uses. In a setting where the use of very low-rate active ingredients has increased, the exposure of crops to unintended pesticide use is increasing. The EPA has published guidance on what levels of pesticide comingling are allowable, but recent field experiences indicate these levels are not protective for growers.

Rinsate disposal provides another challenge for applicators. Labels give directions on how to dispose of rinsate, but often they refer you to other sources or are vague. Local, state, and federal laws impact pesticide waste disposal methods. Depending on the active ingredient, the waste may be considered a hazardous waste and require special handling and disposal strategies. Rinsate can be used to mix pesticides, but issues of storage, compatibility, and exceeding label-listed application rates can be a concern. Engineering controls can be used to dispose of rinsate in the field or to reduce the amount of rinsate generated. New approaches for rinsate or wash water disposal have been researched in Europe and in the United States. These approaches use biological processes to break down rinsates, similar to how pesticides break down in the field. Research has shown these disposal systems have promise, but they also create new questions concerning permitting, long-term use, and disposal of contaminated treatment media.

# Water Quality Research in Illinois

*George F. Czapar*

Water quality is an issue that affects everyone, regardless of where you live. It continues to be one of the biggest challenges facing agriculture. Specifically, there are concerns that excess nutrients and sediment are causing impairment of rivers, streams, and lakes.

Although everyone wants clean water, there are different expectations, definitions of impairment, and approaches for protecting water quality. Water quality standards, based on the best available science, are necessary to help prioritize protection efforts. These standards not only consider runoff and drainage from agricultural fields but also discharges from factories and sewage treatment plants. Thus, they directly affect both rural and urban residents.

The Illinois Council on Food and Agricultural Research (C-FAR) is supporting a major research initiative in water quality. The goals of this project are to help develop the scientific basis for nutrient standards in the surface waters of Illinois and to assist in the appropriate development and implementation of total maximum daily loads (TMDLs).

To improve water quality, new information and educational resources must be made readily available. The Illinois Watershed Management Clearinghouse (http://www.watershed.uiuc.edu) provides practical information to local watershed groups and individuals. Watershed management is done at the local level, and this Web site gives groups a common place to go for resources.

The mapping tools linked in the Web site enable the users to get a detailed map of their area and watershed. This information can help guide individual management decisions and is useful for developing nutrient management plans.

# PDA Use and Data Management

*Charles G. Rock*

# Repackaging Bulk Pesticides: What Does FIFRA Allow?

*Dave Fredrickson*

Repackaging of pesticides into bulk containers has been allowed since 1977 under an enforcement policy issued by the United States Environmental Protection Agency. Repackaging of pesticides into reusable containers helps end users by eliminating disposal problems from empty containers. Many Wisconsin firms are involved in bulk repackaging. The term "bulk" means any container with a volume of more than 55 gallons or 100 pounds. Wisconsin's bulk pesticide storage laws share this definition. Our inspections at bulk facilities periodically find violations of the enforcement policy. This article outlines the basic requirements for a bulk repackager of pesticides.

A bulk repackager of pesticide products is considered to be a pesticide producer under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) as amended and accordingly has certain responsibilities. FIFRA requires that each pesticide product be registered before its sale and distribution.

The U.S. EPA exempts bulk repackagers from these registration requirements only if they comply in all respects with U.S. EPA's Enforcement Policy Applicable to Bulk Shipment of Pesticides as amended (the Bulk Policy). To avoid having to register each individual product that you sell or distribute, you must satisfy all of the requirements listed below.

## Establishment Registration

**Each location** involved in bulk repackaging must be registered with U.S. EPA Region 5, as a pesticide-producing establishment. Upon registration, you will be given an EPA establishment number. It is a violation of FIFRA to repackage pesticide products without an **active establishment number**. Establishment numbers identify where a product has been produced or packaged. In cases where a product is found to be contaminated, we need to know where the product came from, and where it may have been repackaged. If you have any questions about establishment registration(s), please contact Gayle Muffit, Pesticide Section U.S. EPA Region 5, in Chicago, at (312) 886-6008.

## Authorization to Repackage/ Repackaging Agreement

Every location where products are repackaged must have a **separate,** written repackaging agreement, **on site,** from each registrant whose products are being repackaged at that site. In cases where the agreements permit other than dedicated containers, written instructions for cleaning nondedicated mini-bulk containers must be in the agreement, or in a separate registrant(s) document. All such agreements

must be available for inspection upon request by U.S. EPA or any agent of U.S. EPA. Personnel at each location must know, understand, and abide by all terms and conditions of the repackaging agreement and any supplemental container cleaning instructions.

## Recordkeeping and Reporting

FIFRA requires pesticide producing establishments to maintain production records and to report to U.S. EPA annually, by March 1, the quantities of each pesticide produced and distributed during the year. The report must be submitted even if there was no production at that site during a particular year. Repackaging is a "production" activity. You must report on the kinds and amounts of products repackaged.

## Operating Procedures

Each location must maintain an adequate supply of registrant's labels. The registrant's label, with the location's EPA establishment number and net contents added to it, must be affixed to every mini-bulk container that has had the registrant's pesticide introduced into it. Since April 1992, any amount of pesticide may be repackaged into bulk containers. This rule means you may repackage only into containers authorized in the repackaging agreement, but never in containers with less than 55-gallon or 100-pound capacity. Where repackaging agreements permit, follow written instructions for cleaning empty containers before introducing a pesticide product that is not the same as the product that formerly occupied the container.

Failure to follow the requirements of the Bulk Policy and the procedures outlined above are violations of federal law and can result in severe penalties. During the last year, several Wisconsin firms have had to pay forfeitures to EPA for failing to file production reports. EPA Region 5 is more interested in gaining the cooperation and compliance of bulk repackagers than in pursuing violations. We urge you to compare your policies and procedures to those outlined above and to initiate prompt corrective action where indicated. If you have questions about repackaging, or any of your responsibilities, please contact the Illinois Department of Agriculture at (217) 785-2427, your pesticide product registrants, or you may call Dea Zimmerman at (312) 353-6344 or David Star at (312) 886-6009, with the Pesticides Section at U.S. EPA Region 5.

# Agrichemical Facility Containment and On-Farm Storage Status Report

*Warren D. Goetsch*

The agrichemical facility containment program was initially established 1989 as a result of the adoption of 8 Illinois Administrative Code 255 (8 IAC 255), which became effective on January 1, 1990. These rules, which became known simply as "Part 255," were drafted by industry, university, and government representatives serving on an ad hoc "bulk rules" committee chaired by the Illinois Department of Agriculture. The original rules have survived these past 14 years without a great deal of change, having been permanently amended only twice, once in 1995 and most recently through the addition of the on-farm storage containment provisions on July 1, 2002.

The development and adoption of this rule signaled a desire on the part of the agrichemical industry in Illinois to be more proactive in terms of facility design, construction, and operation as it related to facility site environmental stewardship. The Illinois General Assembly further defined this desire through the passage of Public Act 86-1172 in 1990 that authorized the Department of Agriculture to conduct an agrichemical facility site contamination study, create an agrichemical incident response program, administer an agrichemical incident response fund, and create a land application authorization program. Since Part 255 was created and implemented, additional programs and rules governing washwater containment areas at lawncare facilities (8 IAC 256), an alternative cooperative groundwater protection program (8 IAC 257), a formal land application authorization program (8 IAC 258), and an agrichemical facility site remediation program (8 IAC 259) have been developed and adopted. The development of each rule and associated program has been a cooperative effort between industry and government. In each case, the overall goal has been one of environmental protection while attempting to consider the specific nuances of the agrichemical industry and its continued viability in an ever-evolving agricultural industry.

## Original Agrichemical Facility Containment Program

Part 255 became effective on January 1, 1990. As a result, the Department of Agriculture has been reviewing, requesting additional information, and approving or denying permit applications for the construction and operation of containment structures and systems at agrichemical facilities in Illinois for about 14 years. During that time, the department has received 1,641 facility registrations and 7,691 permit applications (includes permit renewal requests, amendments, modifications, and new sites) regarding commercial and noncommercial facilities.

The original containment program included a joint permit application review with staff members of the Illinois Environmental Protection Agency (IEPA) that allowed for an IEPA endorsement of the Illinois Department of Agriculture (IDA) permit in lieu of an IEPA water pollution control or air pollution control permit. Although sometimes slow and tedious, this process has proved to be successful, and very few of the original IEPA air or water pollution control

permits remain. There are currently 1,034 active sites in the state operating under permits issued by the Illinois Department of Agriculture; 712 of these sites include bulk liquid fertilizer storage and 673 of these sites include bulk liquid pesticide storage. The department has permitted containment structures and systems designed to protect 4,388 bulk pesticide storage tanks with a combined storage volume of 13,987,337 gallons (an average of 3,188 gallons per tank). There are currently 129 permitted sites in the state that use one or more storage tanks with a capacity of 100,000 gallons or greater. There are also 765 sites in the state that have bulk dry fertilizer storage. The overall program created for the containment of commercial and noncommercial facilities has remained essentially unchanged from the inception of the program and continues to successfully operate today.

## Lawncare Washwater Containment Program

Although the Lawncare Products Application and Notice Act (415 ILCS 65) was created by the Illinois General Assembly at about the same time as the adoption of the Part 255 rules, the current program was not established until a few years later. The original statute was became effective January 1, 1990. It was subsequently amended in September 1992 to allow for Department of Agriculture issuance of permits for the construction and operation of washwater containment areas very similar to the original agrichemical facility containment program. The implementing rules, 8 IAC 256, were adopted and became effective February 9, 1993. The containment provisions of the Lawncare Products Application and Notice Act were further amended in 2001 to refine the requirements and make them even more consistent with the agrichemical facility containment program. The current statute and associated rules require the construction and operation of rinsing and loading pads used for the capture of spills or washing or rinsing of pesticide residues from various application-related items as well as the loading of lawncare products for distribution to a customer. The applications qualifying for such protections are limited to pesticides applied to land areas covered with turf kept closely mown or land area covered with turf and trees or shrubs.

The Department of Agriculture currently categorizes 1,150 facilities statewide as active and possibly being subject to these requirements. The department has determined that 434 of these sites are currently exempt due to the nature of their current business activities, and an additional 51 sites have been recategorized as being closed. Permits have been issued to the owners or operators of 577 sites. There are currently 78 facility sites with pending permit applications.

An alternative compliance method to the construction and operation of a permitted loading and washwater containment structure is available to facility owners and operators and involves the use of a neighboring, permitted, lawncare or agrichemical containment facility. There are currently 219 facilities in the state operating through such an agreement with a neighboring facility.

The remaining 276 facilities are not currently permitted or have a permit pending or are operating "out-of-compliance" and are therefore possibly subject to enforcement actions. Pursuant to the provisions of the statute, such facilities could face fines of $100, $200, or $300 for the first, second, and subsequent violations, respectively. The Department of Agriculture continues to work with the owners and operators of these sites to move them towards total compliance with the statute and rule.

## Alternative Cooperative Groundwater Protection Program

One of the compelling reasons for the agrichemical industry to support and assist in the development of the original agrichemical facility containment program was the passage of the 1987 Illinois Groundwater Protection Act (IGPA). In that act, agrichemical facilities that were located within a setback zone of a private or community water supply well (private potable wells, 200 feet; community water supply wells, usually 200 or 400 feet as established by an Illinois Environmental Protection Agency wellhead survey but could be extended by action of local government to a maximum of 1,000 feet) or regulated recharge area of a community water supply well (established by a formal rule-making through the Illinois Pollution Control Board with a maximum distance of 2,500 feet) were identified as potential primary sources of groundwater contamination. The IGPA required the adoption of various structural and operational protection requirements to be incorporated into such facilities that remained in proximity (within the setback zone or regulated recharge area) to community water supply wells as established by a formal rule-making conducted through the Illinois Pollution Control Board. During that rule-making process, it became apparent that although the requirements in the Part 255 rule would satisfy most, but not all the structural and operational requirements required by the Groundwater Protection Act. Specifically, some type of groundwater monitoring was needed at the facility site. In response, industry,

in cooperation with the IDA and IEPA, supported amendments to the Illinois Environmental Protection Act that allowed for the development and implementation of an alternative groundwater protection program for such sites. A formal rule (8 IAC 257) was developed and adopted to create an alternative program operated by the Department of Agriculture that included compliance with the original containment program as well as the design and operation of groundwater monitoring programs to ensure water supplies remained free of impacts from such sites. These rules became effective in January 1994. More than 20 facilities have used this program since that time as an alternative to the requirements established by the Illinois Pollution Control Board (35 IAC 615 and 35 IAC 616).

## Land Application Program and AFRAP

As noted earlier, Public Act 86-1172 amended the Illinois Pesticide Act and included provisions for an agrichemical facility site contamination study and a land application program among several others. These mandates eventually led to the development and adoption of two rules intended to assist the owners and operators of agrichemical facilities in the appropriate remediation of sites that had become contaminated due to the uncontrolled release of agrichemicals. Such programs are very important in that they are intended to encourage proper site "cleanup" while providing both environmentally responsible and economically reasonable approaches to such activities.

The land application authorization program, which provides for Department of Agriculture review and approval of the application of agrichemical-contaminated soil and groundwater onto agricultural land at agronomic rates, was originally established as a pilot program by the 1990 legislation and was permanently established by rule (8 IAC 258) in 1999. The department has issued 103 land application authorizations since 1999, authorizing the application of 233,302 tons of agrichemical-contaminated soil and 1,383,013 gallons of agrichemical-contaminated water onto agricultural lands, applied at agronomic rates. Projects have been conducted statewide; facilities located in 50 of the 102 counties have conducted projects. The majority of these authorizations have been associated with soil or groundwater originating from retail storage and handling facilities. However, the Illinois Pesticide Act was amended in 2001 to allow for authorizations to address agrichemicals released in transit from the facility site to the intended field of application. This change in authority has proven to be very useful in that it allows for a more economical and reasonable method for addressing the clean up of such incidents. , In 2003, for example, 12 of the 19 applications received by the department were associated with the remediation of roadside spills. These authorizations allowed the impacted soils and water to be applied to farmland where the agrichemicals could be used for their originally intended purposes (crop production) rather than being permanently entombed in a landfill.

The second program administered by the department to facilitate environmentally responsible remediation of agrichemical facilities is the Agrichemical Facility Response Action Program (AFRAP), which was authorized by the General Assembly in amendments to the Illinois Pesticide Act in 1995 and 1997. The program was formally established by rule (8 IAC 259) in February 2002 and includes default cleanup objectives for various agrichemicals as well as a process by which a facility can establish site-specific cleanup objectives based of actual hydrologic and soil characteristics of the site. Although the program has yet to be used by the industry, it is available when needed.

## On-farm Storage Facility Containment Program

The most recent amendments to the original agrichemical facility containment program rules added a definition for an on-farm storage facility, as well as specific containment requirements for such sites and became effective July 2002. These amendments require the design, construction, and operation of secondary containment structures and systems for a site meeting the definition of an on-farm storage facility. These amendments established an initial compliance deadline for the registration of existing on-farm storage sites of March 31, 2003. To date, the Department of Agriculture has received registration forms from 150 sites that are further described as follows:

| | |
|---|---|
| Facilities with bulk liquid fertilizer storage | 145 |
| Facilities with bulk pesticide storage | 5 |
| Facilities with bulk dry fertilizer storage | 7 |
| Facilities with bulk dry pesticide storage | 0 |

The registration forms indicate that, in terms of containment, 23 facilities or 15.9% of the registered bulk liquid fertilizer storage (tanks greater than 5,000 gallons) sites (145) presently incorporate some form of containment structure or system. The forms also indicate that there are 393 storage tanks located at these 145 facilities with a total on-farm liquid fertilizer storage volume of almost 5.4 million gallons. The largest tank has a volume of just more than 270,000 gallons. The average number of liquid fertilizer tanks

at an on-farm site is 2.7 per facility with an average tank capacity of 13,700 gallons.

Only five on-farm storage facilities registered with the department are used to store bulk liquid pesticides (storage tanks greater than 300 gallons). There are presently 11 bulk pesticide storage tanks at on-farm sites registered with the Department of Agriculture, with an overall capacity of 27,050 gallons. The largest bulk pesticide storage tank registered has a capacity of 3,000 gallons. Thus, there is an average of 2.2 tanks per site with an average capacity of 2,460 gallons per tank.

Seven on-farm facilities registered with the department include bulk dry fertilizer storage structures, each site using one storage building. The largest building has a capacity of 360 tons, whereas the average capacity is 157 tons. The overall storage capacity of these seven sites is 1,098 tons.

The second deadline associated with the containment of existing on-farm storage facilities is March 31, 2004, for the submittal of a permit application and construction plans and specifications for the proposed containment structures or systems. The Department of Agriculture has already received three such applications. After a complete review of the applications, the department has issued two permits, one for a bulk dry fertilizer storage building and one for a bulk liquid fertilizer secondary containment structure.

The final deadline for existing on-farm storage sites addresses the completion of any necessary secondary containment construction. All existing facilities are required to complete construction of their permitted secondary containment structures and systems on or before June 30, 2005.

With regard to new sites or structures to be built after the effective day of the rule amendments (July 1, 2002), all such facilities must be permitted by the department and construction of the secondary containment structure or system must be completed before the facility being placed into service.

## Summary

Each of these programs has been intended to ensure the safety of the environment while attempting to preserve the viability of the agrichemical industry in Illinois. In several cases, the provisions of these programs have been developed specifically for this industry. The success of each program would not have been possible without the full cooperation and support of the regulated community, the agrichemical industry in Illinois. In terms of the newest program, the on-farm storage containment amendments to Part 255 will not be successful without the continued cooperation of the agrichemical industry. The industry leaders that stepped forward and assisted in the development of those original rules that impacted their commercial sites must work with their growers/customers to ensure that there is a good understanding of these new requirements for on-farm facilities. The commercial agrichemical dealers will be the ones servicing or filling these on-farm storage structures, thus they will be in the best position to pass on information to the grower regarding containment requirements. The Department of Agriculture and its staff will make compliance outreach efforts, but it will again take industry and government working together to ensure the success of this program.

## Acknowledgement

I acknowledge the assistance of several staff members of the Illinois Department of Agriculture's Bureau of Environmental Programs for efforts in tabulating various data for this article. Specifically, I thank Gerald Kirbach, Doug Owens, Eric Behrens, Richard Royer, and Valerie Booth for assistance.

# Off-Label Applications and Pesticide Transportation Incidents

*Gerald Kirbach*

## Pesticide Transportation Incidents

The agricultural pesticide industry has continued to undergo far-reaching changes over the past few years. Consolidation of pesticide registrants/manufacturers, equipment manufacturers, seed production, and fertilizer distributors has become the norm as the agricultural sector "slims" down. Margins and service income still remain under a downward pressure.

As dealers and producers continue to look for any means to increase profitability, resources become strained and negative consequences can result. In my opinion, the industry still has an ongoing love affair with trucks and tanks. They never let go of a truck until it just collapses. How many of you purchase a new vehicle for "tendering" loads to the application equipment? How many times are tanks continually used until they develop a leak?

Proper equipment maintenance has always been a priority in your industry. Application technology, new equipment costs, and pressure on the billable costs of service to your customer base have driven the need to use vehicles and tanks to a point that stretches those resources beyond their serviceable life. In this presentation, I share some transportation incidents that involved tender or supply vehicles as well as application equipment and review the following:

1. Equipment failure
2. Area impacted
3. Complaint handling
4. Response actions
5. Stewardship
6. Follow-up activities

### *Equipment Failure*

This year the Illinois Department of Agriculture experienced a number of incidents that involved a breach in the integrity of polyethylene tanks during transport. In all of the cases, the tank had a major breach in the integrity of the vessel itself. The impact from these types of tank failures required additional remedial activities due to the increased size of the area impacted. The department was unable to determine the age of these tanks, but most seemed to have several years use or were stored in a manner that exposed the tank to the weather throughout the year.

Most of the incidents this year involved liquid fertilizer or a pesticide/liquid fertilizer tank mix. All but two of the incidents involved commercial dealers. Those two incidents involved growers moving product from the storage site to the field of application. One incident was a catastrophic release of the entire load while in transit. The other involved a failure of a valve causing release of product along a roadside for 4 miles and through the property to the scale house.

Tank failures during transportation present significant challenges due to the volume of material released. The surrounding terrain, speed of the vehicle, climatic conditions, point of release and time required to respond all have a dramatic effect on the environmental impact of the incident.

One such incident was the result of a seam failure on the tank. The tank split in half on a bumpy rural blacktop road, and the curvature of the tank halves caused the product to be hurled to both sides of the highway in a residential area.

### *Area Impacted*

One incident involved the failure of a tank that ruptured and landed on the side of an embankment. Product was removed from the bottom of the ditch. The remaining product on the embankment migrated to an overflow water impoundment that drained to a small lake that supplied water to 25 homes. Accurate and complete assessment of the release site and surrounding impacted area is critical to successful planning and remediation.

### *Complaint Handling*

The department received several calls from an impacted property owner complaining about the response received from the responsible party. After discussion, the complainant had been told not to worry that no one would have to mow the lawn for several months. Timely and professional handling of all complaints can reduce the potential for litigation.

### *Response Actions*

All response actions should be timely and appropriate and include proper reporting. The department had received an anonymous "tip" that there had been release of 28% in a remote area off of a blacktop road. After investigation of the site, investigators discovered that the responsible party had lost 1,000+ gallons of 28% nitrogen solution, but had "the situation under control." Always report an incident even if there is a question about exceeding the reporting threshold.

### *Stewardship, Follow-up Activities*

The responsible party has an obligation to make every effort to restore the impacted property to the same condition that existed before the event, including replacement of excavated soil, sod, or reseeding and replacement of trees, if needed. The property owners normally have a vested interest and feel that something has been taken away from them.

### *Off-Label Applications*

The Department of Agriculture continues to receive several complaints involving the misuse of a pesticide. More than 50% of these complaints involve an individual failing to follow the label. Please remember that the label is the state-mandated requirement for all pesticide applications. Failure to follow the label is an enforceable violation that can lead to actions taken against the responsible person by the department as well as civil litigation by the complainant.

The department still seeks enforcement action against several individuals for failure to follow an atrazine label that has been in effect since the early 1990s. Please take the time to familiarize yourself and any of your employees with the products being applied, including restrictions, environmental hazards, and protective equipment.

In summary, I hope this presentation has raised your awareness about the challenges associated with the agricultural industry outside of the "normal" things encountered day to day by providing insight into good stewardship and simply being a good neighbor. All of us encounter situations during the application season that are stressful, but it is my hope that I have started the thought process for your planning to prevent agrichemical releases and for the contingency planning needed in the event of a catastrophic release.

# Product Update for Insect Management

*Kelly Cook and Kevin Steffey*

This proceedings article is an overview of field crop insect-control products that have been recently registered or had label revisions. Efficacy data are not presented. Efficacy data compiled from several sources can be obtained in a handout distributed at this conference.

The most recently registered insect-control products and products with label revisions can be categorized as follows:

- "conventional" chemical insecticides,
- insecticides intended for use in organic production systems,
- insecticidal seed treatments, or
- transgenic crops modified to express insecticidal proteins.

Some of the properties and intended uses for products within each of these categories are discussed. The companies that manufacture or distribute the products are listed alphabetically within each category, and the products are listed alphabetically within each company.

The inclusion of target insects and time of application within the article does not necessarily represent a recommendation by entomologists at the University of Illinois. For example, we seldom make recommendations for use of soil insecticides for control of seedcorn maggot. For specific recommendations from the University of Illinois, consult current issues of the *Illinois Agricultural Pest Management Handbook* and the *Pest Management & Crop Development Bulletin*. Included in the text is abridged label information. Some critical use information is included in the footnotes. Please recognize that this information has been transposed from the label and mistakes are possible. Producers should obtain a label, understand all precautions, and follow all directions.

## Conventional Chemical Insecticides

Although most of the focus this past year has been on the commercialization of transgenic corn rootworm hybrids and seed treatments, there have been some additions and revisions to conventional insecticide labels.

### *Dow Agrosciences LLC*

**Intrepid 2F** (active ingredient methoxyfenozide) Intrepid 2F, an insect growth regulator, has been on the market for several years. Some supplemental labels also have been issued. In March, 2003, a new label was issued. Intrepid 2F belongs to the diacylhydrazine class of insecticides and has a novel mode of action that mimics the natural insect molting hormone of lepidopterans. Upon ingestion, the larvae undergo an incomplete and lethal premature molt. This insecticide is highly selective and has virtually no activity on any other insects or arthropods. Intrepid 2F is now registered for use against European corn borer and southwestern corn borer in corn (field, sweet, and seed) at a rate of 4 to 8 ounces per acre. The maximum amount of Intrepid 2F allowed is 16 ounces per acre per application or 64 ounces per acre

per season. The preharvest interval for field corn is 21 days.

Methoxyfenozide is highly toxic to fish and aquatic invertebrates, so caution should be taken to avoid drift and runoff into bodies of water. Mammalian toxicity is moderate to low: oral $LD_{50}$ value for rats is >5,000 mg/kg, and the dermal $LD_{50}$ value for rats is >2,000 mg/kg. The use of methoxyfenozide in highly permeable soils and where water tables are low may result in groundwater contamination.

### *FMC Corporation*

**Mustang Max** (active ingredient *zeta*-cypermethrin) Mustang Max, a pyrethroid, is a refined-isomer formulation that replaced Mustang in the spring of 2003. Table 1 provides an abridged list of insects for which Mustang Max is labeled, with recommended rates of application. Some critical use information is included in the footnotes.

Like all pyrethroids, *zeta*-cypermethrin is highly toxic to fish and aquatic invertebrates, so caution

**Table 1 Abridged label information for control of insects in alfalfa, corn, sorghum, soybean, and wheat with Mustang Max.**

| Crop | Insect | Rate of Application |
|---|---|---|
| **Alfalfa**[1] | Alfalfa caterpillar, alfalfa weevil, cutworms, meadow spittlebug, potato leafhopper | 2.24–4.0 oz/acre |
| | Grasshoppers, plant bugs | 2.8–4.0 oz/acre |
| **Corn** (field and seed) and popcorn (at plant)[2] | Cutworms | 0.16 fl oz/1,000 ft of row |
| | Cutworms | 1.28–2.8 oz/acre |
| | Corn rootworm adults, European corn borer, flea beetles, grasshoppers, hop vine borer, Japanese beetle adults, sap beetles, southern corn leaf beetle, southwestern corn borer, stalk borer, stink bugs, webworms | 2.72–4.0 oz/acre |
| | Armyworms, chinch bug, fall armyworm | 3.2–4.0 oz/acre |
| | Corn earworm | 1.76–4.0 oz/acre |
| **Sorghum** (grain)[3] | Cutworms, sorghum midge | 1.28–4.0 oz/acre |
| | Corn earworm, webworms | 1.76–4.0 oz/acre |
| | Chinch bug, grasshoppers | 3.2 to 4.0 oz per acre |
| **Soybean**[4] | Cutworms, thistle caterpillar | 1.28–4.0 oz/acre |
| | Bean leaf beetle, blister beetles, corn earworm, green cloverworm, Japanese beetle adults, Mexican bean beetle, potato leafhopper, soybean aphid, woollybear caterpillars | 2.8–4.0 oz/acre |
| | Grasshoppers, loopers, stink bugs | 3.2–4.0 oz/acre |
| **Wheat**[5] | Armyworm, cereal leaf beetle | 1.76–4.0 oz/acre |
| | Grasshoppers | 3.2–4.0 oz/acre |

[1] Do not make applications less than 7 days apart. A maximum of 0.025 pound of active ingredient per acre may be applied per cutting and a maximum of 0.075 pound og active ingredient per acre per season. Applications may be made up to 3 days of cutting or grazing. Do not apply to mixed stands with intentionally grown forage grasses and/or legumes.

[2] The preharvest interval (PHI) is 30 days for grain and fodder and 60 days for forage (silage). Do not apply more than 0.10 pounds of active ingredient per acre per season, including at-planting plus foliar applications of Mustang Max.

[3] The PHI is 14 days for grain and stover and 45 days for forage (silage). Do not make applications less than 10 days apart. Do not apply more than 0.15 pound of active ingredient per acre per season.

[4] The PHI is 21 days. Do not graze or harvest treated soybean forage, straw, or hay for livestock feed. Do not make applications less than 7 days apart. Do not apply more than 0.15 pound of active ingredient per acre per season.

[5] The PHI is 14 days for grain, forage, and hay. Do not make applications less than 14 days apart. Do not apply more than 0.125 pound of active ingredient per acre per season.

**Table 2 Abridged label information for control of insects in corn with Empower.**

| Crop | Insect | Rate of Application |
|---|---|---|
| Corn (grain, silage, and seed), popcorn (at plant use)[1] | Corn rootworm larvae (Mexican, northern, southern, western), cutworms, wireworms, seedcorn maggot, seedcorn beetle, white grubs | 6.4–8.0 oz/1,000 ft of row (T-band) |
| | Cutworms, wireworms, seedcorn maggot, seedcorn beetle, white grubs | 3.2–8.0 oz/1,000 ft of row (in-furrow) |
| | Rootworm larvae | 8.0 oz/1,000 ft of row (in-furrow) |
| | European corn borer (1st generation), fall armyworm, southwestern corn borer, armyworm | 3.5–8.7 oz/acre |

[1] The preharvest interval is 30 days. Do not graze livestock in treated areas or cut treated crops for feed within 30 days of last application. Do not apply more than 0.1 pound of active ingredient per acre per season as an at plant application. Do not apply more than 0.3 pound of active ingredient per acre per season, including at plant plus foliar applications. Do not apply to soil where there is greater than 30% cover of crop residue remaining.

should be practiced to avoid drift or runoff into bodies of water. Mammalian toxicity is moderate to low, depending upon exposure: the oral $LD_{50}$ value for rats is 157 mg/kg; the dermal $LD_{50}$ value for rats is >5,000 mg/kg. *zeta*-Cypermethrin is rapidly degraded in the soil, with a half-life of 2 to 4 weeks. It has a high affinity for organic matter and is not mobile in the soil.

### *Helena Chemical Company*

**Empower** (active ingredient bifenthrin)
Empower, a pyrethroid, is a granular insecticide with the same active ingredient as Capture 2EC. Empower can be applied at planting in a band or in the seed furrow for control of corn rootworm larvae (band only), cutworms, seedcorn maggot, white grubs, and wireworms. The application rates are 6.4 to 8 ounces of product per 1,000 feet of row in a band and 3.2 to 8 ounces per 1,000 feet of row in the seed furrow. Empower also can be used for control of first-generation European corn borer, fall armyworm, and southwestern corn borer at 3.5 to 8.7 pounds of product per acre applied over the foliage. Abridged label information for Empower can be found in Table 2. Some critical use information is included in the footnotes.

Bifenthrin, like all pyrethroids, is extremely toxic to fish and aquatic invertebrates. Care should be taken to avoid drift or runoff into bodies of water. Mammalian toxicity is low: the oral $LD_{50}$ value for rats is 7,431 mg/kg; the dermal $LD_{50}$ value for rabbits is >5,000 mg/kg. Bifenthrin has moderate stability in the soil under aerobic conditions (half-life ranges from 65 to 125 days, depending on soil type). It has a high affinity for organic matter. Bifenthrin is not mobile in the soil, thus having little potential movement into groundwater.

**Empower²** (active ingredient bifenthrin)
Empower² is a granular insecticide with the same formulation as Empower. However, Empower² contains Indole-3-Butyric acid, a plant growth regulator. For corn (grain, silage, and seed), label recommendations remain the same as for Empower.

## Insecticides Intended for Use in Organic Production Systems

The number of organic farms in Illinois is on the rise and so is the request for information about treating insect pests in organic production systems. Because of the increase in organic farming, we are including an insecticide Entrust in this product update.

### *DOW Agrosciences LLC*

**Entrust** (active ingredient spinosad)
In 2003, Dow AgroSciences LLC received notification from the U.S. EPA that their insecticide Entrust had been certified for use in organic production systems. Entrust has the same active ingredient (spinosad) of the Naturalyte™ insecticide Tracer. However, Entrust has been formulated specifically for use by organic growers. It is labeled for use in cereal grains, corn, and soybean. Use rates are 0.5 to 2 ounces of product per acre, depending upon the crop and target pest. Abridged label information for Entrust can be found in Table 3. Some critical use information is included in the footnotes.

Spinosad has a mode of action different from the mode of action of organophosphates, carbamates, and pyrethroids. It causes persistent activation of nicotinic acetylcholine receptors by a distinct and novel mechanism. Spinosad is slightly toxic to aquatic organisms, but caution should still be practiced to

avoid drift or runoff into bodies of water. Mammalian toxicity is extremely low with an oral $LD_{50}$ value for rabbits of >5,000 mg/kg and a dermal $LD_{50}$ value for rats of >5,000 mg/kg. The half-life of spinosad in soil is 9 to 17 days.

## Insecticidal Seed Treatments

The seed treatment discussed in this section is applied to corn seed before it is bagged. It is not to be confused with hopper-box treatments (e.g., Agrox and Kernel Guard) applied to the seed immediately before planting.

Insecticidal seed treatments for control of several soil-inhabiting insects in corn have become legitimate alternatives to granular and liquid soil insecticides. In general, performance of seed treatments for control of corn rootworm larvae in insecticide efficacy trials has not been as consistent as the performance of the soil insecticides. When infestations of corn rootworm larvae are high, seed treatments may not provide acceptable control. However, all of the seed treatments have provided good protection of the seed against wireworms and seedcorn maggots. Efficacy data for the seed treatments of other soil-inhabiting insects in corn are not abundant. Therefore, some of the label claims are based upon results from only a few research trials.

### *Bayer CropScience (and Gustafson LLC)*

**Poncho 600** (active ingredient clothianidin)
Poncho 600 is a seed-applied insecticide for corn. This nicotinoid insecticide is closely related to imidacloprid, the active ingredient in both Gaucho and Prescribe. Its systemic properties are similar to those of imidacloprid. In 2004, Poncho 600 will be available at two application rates under the names Poncho 250 (0.25 mg of active ingredient per kernel) and Poncho 1250 (1.25 mg of active ingredient per kernel). Poncho 250, the lower application rates is labeled to protect corn from early season injury caused by cutworms, flea beetles, seedcorn maggot, and wireworms. Poncho 1250 offers a higher protection rate that includes the aforementioned insect pests as well as billbugs and corn rootworms.

Mammalian toxicity to clothianidin is low: oral $LD_{50}$ value of rats is >5,000 mg/kg and dermal $LD_{50}$ value of rats is >5,000 mg/kg. Clothianidin is a systemic insecticide. Depending on environmental and soil conditions, clothianidin can be persistent and mobile and has the potential to leach to groundwater. Clothianidin is also toxic to aquatic invertebrates.

## Transgenic Crops

In a time when the use of transgenic crops is increasing, two new transgenic corn events for insect resis-

**Table 3 Abridged label information for control of insect pests of corn and soybeans with Entrust.**

| Crop | Insect | Rate of Application |
|---|---|---|
| Cereal grains (barley, buckwheat, grain amaranth, milo, oats, pearl millet, proso millet, rye, sorghum, triticale, wheat)[1] | Cereal leaf beetle | 0.5–2 oz/acre |
| | Armyworms, corn earworm, southwestern corn borer, webworms | 1–2 oz/acre |
| Corn (field, sweet, popcorn, and seed)[2] | Armyworms, European corn borer | 0.5–2 oz/acre |
| | Beet armyworm, corn earworm, southwestern corn borer, western bean cutworm | 1–2 oz/acre |
| Soybean[3] | Green cloverworm, soybean looper, true armyworm, velvet bean caterpillar | 1–2 oz/acre |
| | Armyworms (such as fall armyworm, yellowstriped armyworm, beet armyworm), corn earworm, saltmarsh caterpillar[4] | 1.25–2 oz/acre |

[1] Do not apply more than 5.6 oz of Entrust per acre per year. The preharvest interval (PHI) is 21 days for grain or straw harvest and 14 days for forage or hay harvest.
[2] Do not apply more than 3.75 oz of Entrust per acre per year. The PHI is 28 days for grain or fodder harvest and 7 days for forage harvest.
[3] Do not apply more than 3.72 oz of Entrust per acre per year. The PHI interval is 28 days. Do not feed treated forage or hay to meat or dairy animals.
[4] Soybean looper, velvetbean caterpillar, and beet armyworm usually do not occur is Illinois. Species of armyworms rarely cause economic damage in soybean in Illinois.

tance recently have been commercialized. Through 2002, only YieldGard Corn Borer was commercially available to offer insect resistance in corn. Herculex I Insect Protection was newly available in 2003, and YieldGard Rootworm also became available, on a limited basis, in 2003. YieldGard Rootworm hybrids will be more widely available in 2004.

### *Dow Agrosciences LLC*

**Herculex I Insect Protection** (expresses the Cry1F insecticidal protein)

Herculex I was commercially available in Mycogen Seeds hybrids for the first time in 2003. Corn seed containing Herculex I Insect Protection expresses the Cry1F protein, which is effective against certain caterpillars. Herculex I Insect Protection protects corn against the European corn borer, southwestern corn borer, black cutworm, and fall armyworm. It also offers moderate suppression of the corn earworm. Herculex I contains a different protein than YieldGard Corn Borer products, which contain the Cry1Ab protein. Corn seed containing Herculex I Insect Protection is tolerant to glufosinate-ammonium herbicides (LIBERTY® herbicide).

### *Monsanto Company*

**YieldGard Rootworm** (expresses the Cry3Bb1 insecticidal protein)

Monsanto Company received registration approval from the U.S. EPA for the sale of YieldGard Rootworm corn hybrids in February 2003. YieldGard Rootworm hybrids use the transgenic event MON 863 and express the Cry3Bb1 protein, specific to corn rootworm larvae. YieldGard Rootworm hybrids do not provide protection from adult corn rootworm feeding. Moreover, growers should anticipate finding adult corn rootworms in their YieldGard Rootworm fields. The adult rootworms include immigrants from other areas as well as those that have emerged from the field itself. Although the root systems are protected very effectively against larval injury by YieldGard Rootworm hybrids, they are low to moderate in their expression of the Cry3Bb1 protein. Roots may show visible signs of larval feeding or scarring, but the extent of larval rootworm injury should not be economic. YieldGard Rootworm hybrids have been tested by university and company personnel for several years. They were also available on a limited basis in 2003, and the results have been impressive. Information for research trials have shown that the transgenic rootworm protected hybrids provided more consistent protection against rootworm larvae injury than insecticides and insecticidal seed treatments.

For control of secondary insect pests that are not controlled by the Cry3Bb1 protein, all YieldGard Rootworm hybrids will be treated with Poncho (clothianidin, 0.25 mg of active ingredient per kernel). Monsanto Company hopes to release products containing both YieldGard Rootworm (MON 863) and YieldGard Corn Borer (MON 810) in the near future as YieldGard Plus (not yet registered by the U.S. EPA). Undoubtedly, YieldGard Rootworm corn hybrids offer producers an excellent pest management tool for corn rootworms. However, it is extremely important to follow insect resistant management strategies to circumvent the development of resistance to this and other transgenic products. Please refer to the article "Insect Resistance in the Corn/Soybean Cropping System; Issues and Management" in this proceedings (pp.13-16) for more information about insect resistance management strategies.

# Product Update in Weed Management

*Aaron G. Hager*

## BASF Corporation

**Prowl $H_2O$** is new water-based formulation of pendimethalin. This formulation contains 3.8 pounds of active ingredient per gallon (Prowl EC contains 3.3 pounds of active ingredient per gallon), has much less odor than the EC formulation, and stains on clothing and equipment are easier to remove. The manufacturer reports that Prowl $H_2O$ washes off surface residue easier and has less volatility than the EC formulation. Labeled uses for Prowl $H_2O$ and Prowl EC are virtually identical.

**Distinct 70WDG (dicamba + diflufenzopyr)** is now labeled for postemergence applications on popcorn. Before applying to popcorn, verify the selectivity of Distinct on the popcorn hybrid with your local seed company or supplier.

During September 2002, BASF sold its **acifluorfen** (Ultra Blazer, a component of Storm) herbicide business to United Phosphorus Ltd. (UPL). United Phosphorus Inc., the North American subsidiary of UPL, will be marketing acifluorfen products in the United States.

BASF is expecting a registration in Illinois for **Paramount (quinclorac)** use in sorghum.

## Bayer CropScience

**Equip 32WDG (foramsulfuron + iodosulfuron),** first commercialized during the 2003 growing season, is used for postemergence control of weed species in all types of field corn. Equip should not be applied to sweet corn, popcorn, or corn grown for seed. Equip is a premix product containing the same active ingredient as Option (foramsulfuron), and iodosulfuron for improved control of certain broadleaf weed species. Broadcast applications of Equip can be made when corn is 0 to12 inches in height or when corn is in the emergence through V4 growth stage, whichever is more restrictive. Equip should be applied at 1.5 ounces per acre; only one application per growing season is allowed. Methylated seed oil plus a nitrogen fertilizer is the preferred additive system.

Equip controls several grass and broadleaf weed species. The 1.5-ounce use rate of Equip contains slightly less foramsulfuron than a 1.5-ounce use rate of Option, so control of certain grass species (woolly cupgrass, yellow foxtail, and green foxtail) may be less with Equip than with Option.

## Dow AgroSciences

**Keystone LA (acetochlor + atrazine)** is a premix containing 4 pounds of acetochlor and 1.5 pounds of atrazine per gallon. Keystone LA can be applied to field corn, production seed corn, silage corn, and popcorn up to 30 days before planting, preplant incorporated, preemergence, and postemergence up to 11-inch-tall corn. Application rates vary according to soil texture and organic matter content, tillage system, and application timing, and range from 1.6 to 3 quarts per acre. An applica-

tion rate of 2 quarts per acre provides 2 pounds of acetochlor and 0.75 pounds of atrazine.

**Stinger (clopyralid)** was registered for use in sweet corn and popcorn during 2003. Applications of 1/3 to 2/3 pint per acre can be made to popcorn no taller than 24 inches or sweet corn no taller than 18 inches. Do not apply Stinger within 30 days of harvest for ears and forage and 60 days of harvest for stover.

Other label changes from Dow AgroSciences include the rotational interval for oats was reduced from 30 months (plus a successful bioassay) to 9 months for **FirstRate**, and methylated seed oil is an approved additive for postemergence applications of **Hornet**.

## Syngenta

**Callisto (mesotrione)** label changes include reducing the maximum amount allowed per acre per season from 10.7 to 7.7 fluid ounces, and changing the rotational intervals for alfalfa, soybean, and sorghum to 10 months from 18 months, next year, and next year, respectively.

**Gramoxone Max (paraquat)** is now labeled for preharvest applications in field corn, popcorn, and sweet corn. Application rates range between 0.8 and 1.3 pints per acre, and all applications should include a nonionic surfactant. Gramoxone Max should be applied after the black layer has formed at the base of the corn kernels and at least 7 days before harvest.

**Lumax (mesotrione + metolachlor + atrazine)** label changes included modifications in rotational intervals for oats (next year), rye (4.5 months), and alfalfa and clover (18 months) from previous intervals of 2 years for each crop.

Syngenta will be introducing a new formulation of **Boundary (metolachlor + metribuzn)** during 2004.

## Valent

**Gangster V (flumioxazin) and FR (cloransulam)** is a new co-pack product combining the active ingredients of Valor 51WDG and FirstRate 84WDG. Use guidelines and restrictions on the Gangster V label are very similar to those listed on the Valor label, whereas the use guidelines and restrictions on the Gangster FR label are very similar to those on the FirstRate label.

# Product Update in Disease Management

*Wayne Pedersen*

Preventive medicine is the key to the control of most plant diseases. Trying to scout and then apply a fungicide to control plant diseases on field crops is expensive and fungicides are often applied too late to achieve control. Therefore, the primary means of controlling diseases of field crops is through an integrated approach, including genetic resistance, crop rotation, row spacing, date of planting, and the application of foliar fungicides or seed protectants when needed.

Fungicide seed protectants are applied to nearly 100% of all inbred and hybrid corn seed. The most common products are Maxim (fludioxonil) + Apron XL (mefenoxam) or Captan + Allegiance (metalaxyl). Recently, Syngenta introduced another fungicide, Dynasty (azoxystrobin), which should improve control of Rhizoctonia root rot. We evaluated the combination of Maxim + ApronXL+ Dynasty compared with Maxim + Apron XL on hybrid corn, and we will repeat these trials in 2004. No definite conclusions could be made on this product at this time. Another major change in seed protectants was the addition of the insecticides Gaucho, Pancho, and Cruiser. Syngenta also introduced a combination of Cruiser + MaximXL + Apron XL + Dynasty and called the combination Cruiser Extreme Pak.

Seed protectants are used much less frequently on soybean than on corn; however, there has been an increase in the past 10 years. Last year, Dean Malvick reported on the introduction of SoyGard™ from Gustafson LLC, which contains two systemic fungicides, azoxystrobin and metalaxyl. For 7 years, we have evaluated numerous fungicide seed protectants on soybean by using several planting dates. All plots were planted no-tillage at approximately 180,000 seeds/acre in 15- or 30-inch row-spacings. Table 1 summarizes the effect of planting date on plant stand and yield over the 7 years.

Foliar fungicides are not commonly used on hybrid corn, but they may increase yield of susceptible hybrids if severe gray leaf spot or common rust is present. The most common products are Tilt

**Table 1. A summary of plant stand and yield from research plots planted at three planting dates in 1997–2003 at the University of Illinois South Farm.**

| Date | Treatment | Population (plants/a) | Yield (bu/acre) |
|---|---|---|---|
| April 10–25 | Control | 101,230 | 51.8 |
| | Maxim + ApronXL | 153,440 | 56.6 |
| April 26–May 4 | Control | 134,380 | 50.9 |
| | Maxim + ApronXL | 163,970 | 54.3 |
| May 10–17 | Control | 146,290 | 51.9 |
| | Maxim + Apron XL | 147,260 | 52,3 |
| | LSD (5%) | 14,111 | 3.3 |

(propiconazole), Quadris (azoxystrobin), and Stratego (propiconazole + trifloxystrobin). Headline, from BASF, is still not labeled on corn, but it should be in the near future.

Foliar fungicides were promoted in the 1980s, but few acres were ever treated. With the risk of soybean rust, several products are being evaluated in foreign countries where rust is present. The only products currently labeled for rust control in soybean in the United States are Quadris (azoxystrobin) and Bravo (chlorothalonil); however, many additional products and combinations of products are being tested.

Fusarium head blight (wheat scab) was a problem in winter wheat in southern Illinois in 2003 and deoxynivalenol (DON) toxin levels were often above 3 ppm, the upper level for human consumption. Trials in Illinois in 2001 and 2002 with Folicur (tebuconazole) showed a significant decrease in scab and DON, but this decrease was not observed in Indiana, Kentucky, or Ohio. At present, there isn't a label for Folicur in Illinois, but it is under consideration.

# Corn and Soybean Nematodes: The Invisible Enemies

*Terry Niblack*

Here's a little true-false test for you. If you answer "false," explain why the statement is false. If you can answer 8 of 10 correctly, you may not need to hear the information that is presented in this session. If your score is 7 or below, I should see you in the audience!

## True or false?

1. I don't have to worry about corn nematodes because I don't farm on sandy soil.
2. Corn nematodes cause $81 million worth of corn yield loss in Illinois alone every year.
3. Corn nematodes are really "needle" nematodes.
4. Damage caused by corn nematodes looks the same in the field as damage caused by soybean cyst nematode on soybean.
5. I use insecticides on corn, so I don't have to worry much about corn nematodes.
6. I grow a soybean cyst nematode (SCN)-resistant soybean variety, so I don't have to worry about SCN problems.
7. SCN causes more yield loss on soybean than all other diseases and insects combined.
8. All (100%) of the cornfields in Illinois contain corn nematodes.
9. SCN is the only soybean nematode worth worrying about unless I farm in southern Illinois, where root-knot nematode is a threat.
10. Rotation is the best way to limit problems due to nematodes in either corn or soybean.

***Answers:***

1. FALSE; several nematode species prefer heavier soils.
2. TRUE.
3. FALSE; "corn nematodes" includes four major species and several minor ones.
4. TRUE (they're both mostly invisible).
5. TRUE (in some cases).
6. FALSE; just because a variety is labeled "resistant" doesn't mean it has *effective* resistance.
7. FALSE; SCN is the most important soybean problem in most years.
8. TRUE.
9. TRUE.
10. TRUE.

# Field Crop Scouting Calendar and Techniques

*Suzanne Bissonnette and Matt Montgomery*

Effective scouting for key pests in field crops is vital for making good management decisions for yourself or your customers. When and how do you scout for insect, disease, and weed pests in corn, soybean, or alfalfa? A good scouting trip through the field reveals the pests present, the growth stage of the crop and the life stage of the pests, diseased or parasitized pests, pest population increases and decreases, and overall crop condition. Organizing a calendar of scouting trips that is tailored to the growth stage and development of the crop and the pests is essential for your efficiency as a scout. In this session, we discuss key pests and scouting equipment, techniques, and resources to help you use your time efficiently for the best economic return for you and your customers.

# The White Grub Complex in Corn

*Nathan Wentworth and Dave Feltes*

White grubs are among the most important secondary insect pests of corn. Japanese beetle grubs, *Phyllophaga* spp. grubs, and grape colaspis, *Colaspis brunnea*, can significantly reduce plant vigor and population stands, potentially causing significant yield reductions. Japanese beetle adults may interfere with pollination by clipping silks. Unfortunately, a lack of contemporary research hampers our ability to develop effective management plans for these troublesome insect pests. A thorough understanding of the basic biology and life cycle of these insect pests is an important first step to take in developing sound management progress.

## Japanese beetle

Japanese beetle larvae (grubs) are whitish and C-shaped. They are distinguished from other white grubs by the presence of a v-shaped bristle pattern (raster) on the underside of the last abdominal segment. The adult is shiny, metallic green with bronze wing covers. It is distinguished from similar looking beetles by the tufts of white bristles on either side of its abdomen. The Japanese beetle completes its life cycle in 1 year.

## *Phyllophaga* spp.

*Phyllophaga* spp. grubs also are known as "true" white grubs. The larvae are whitish and C-shaped and are distinguished from other white grubs by two parallel rows of bristles on the raster. The adult is reddish brown to black. True white grubs require 3 years to complete their life cycle.

## Grape colaspis

Grape colaspis larvae are ⅛–⅙ in. in length. They are plump, comma-shaped, and white with a brown head capsule. The adult is tan with numerous tiny punctures on wing covers. The grape colaspis completes its life cycle in 1 year.

Although specific management plans need to be improved upon for these insects, it is imperative to monitor your fields for their presence and damage. Scouting will help you make more informed and hopefully profitable decisions.

## References

Steffey KL. 1999. Grape colaspis, *in* Handbook of Corn Insects (Steffey KL, Rice ME, All J, Andow DA, Gray ME and Van Duyn JW eds), p 85, Entomol. Soc. Am., Lanham, MD.

Rice ME. 1999. White grubs. *in* Handbook of Corn Insects, (Steffey KL, Rice ME, All J, Andow DA, Gray ME and Van Duyn JW eds), pp 115–116, Entomol. Soc. Am., Lanham, MD.

# Pandora's Pond

*Dave Shiley*

In 1995, there were about 89,000 ponds in Illinois, totaling more than 259,000 acres. The Illinois Department of Natural Resources estimates that more than 500 new ponds are constructed each year in Illinois. Each of these ponds serves a variety of uses such as fishing, swimming, water retention, and water for livestock. Although all ponds are not created equal in size, shape and purpose, they all do share the commonality of being an ecosystem, which can be easily thrown out of balance by human activities.

Unintentional chemical contamination from agricultural and urban activities can have negative impacts on aquatic systems. Drift or surface runoff of herbicides can kill aquatic vegetation, in turn causing oxygen depletion in the pond as dead vegetation decomposes. Insecticides reaching the aquatic ecosystem may kill fish directly or reduce their food source if aquatic insect populations are reduced or eliminated.

Intentional killing of aquatic vegetation through the use of copper sulfate and other herbicides during the summer can lead to deoxygenating of the pond and result in a summer fish kill. A balance of aquatic organisms and aquatic vegetation while meeting landowner goals and expectations for the pond can seem impossible; therefore, the biggest management challenge may be education.

Management of fisheries population in ponds used for fishing can be extremely challenging and the "balance" can be disrupted more easily as the size of the pond decreases. Fisheries population management issues are introduced in this presentation.

# Corn Rootworm Management in the Corn/ Soybean Cropping System

*Kevin L. Steffey and Jared B. Schroeder*

Never in the history of corn rootworm management have corn growers been able to select from such a diverse variety of rootworm management tools and tactics—crop rotation, granular and liquid soil insecticides, insecticidal seed treatments, transgenic *Bacillus thuringiensis* (Bt) corn, and control of adults to prevent egg laying. In addition, adaptations by both western corn rootworm, *Diabrotica virgifera virgifera*, and northern corn rootworm, *Diabrotica barberi*, have nullified annual rotation of corn and soybean as an effective rootworm management tactic in expanding areas in the Corn Belt. A variant of the western corn rootworm lays its eggs in crops other than corn, including soybean, in the eastern Corn Belt (Levine et al., 2002). A variant of northern corn rootworm undergoes prolonged diapause (eggs overwinter for two winters) in the western Corn Belt, i.e., the female lays its eggs in corn, and larvae do not hatch until corn is planted 2 years later (Krysan et al., 1986). As a result of these adaptations and the availability of so many control tactics, rootworm management is more complex and challenging than it was only 10 years ago.

This report was developed to support discussion of rootworm management and associated issues in our specialized seminar. During the discussion, we focus on managing corn rootworms in the corn/ soybean cropping system, supporting the discussion with findings from research and survey efforts. At the time this report was prepared, some of the research results were not available. However, results from pertinent research are shared at the seminar and form the basis of the discussion.

## Rootworm Management Options

Following this paragraph is a bulleted list of options for managing corn rootworms in Illinois. Crop rotation, soil insecticides, insecticidal seed treatments, or Bt corn should be considered for rootworm control if densities of adult corn rootworms reach or exceed established economic thresholds. For corn planted after corn, crop rotation or use of a rootworm-control product is warranted in fields in which the average number of rootworm adults was 0.75 or more per plant the previous year. However, this number is merely a guideline and should be adjusted according to plant population and crop rotation (Table 1). For corn planted after soybean, a rootworm-control product is warranted in fields in which the average number of rootworm adults was five or more per yellow sticky trap (Pherocon AM trap) per day. Specifics about these thresholds and associated scouting protocols are available at the University of Illinois IPM Web site at http://www.ipm.uiuc.edu.

- Crop rotation—Crop rotation is still an effective rootworm management tactic in areas where the variant western corn rootworm does not occur. (Refer to the section "Variant Western Corn Rootworms That Lay Eggs in Soybean and Other Crops" in this report for more information.)

**Table 1. Average number of western corn rootworm adults present in cornfields that may produce an economically damaging rootworm population in corn the following year (adapted from Wright et al. 1999, University of Nebraska).**

| | Average no. of adult rootworms | | | |
|---|---|---|---|---|
| | Continuous corn[1] | | First-year corn[2] | |
| Plants/acre | per plant[3] | per ear zone[4] | per plant[3] | per ear zone[4] |
| 14,000 | 1.28 | 0.64 | 0.96 | 0.48 |
| 16,000 | 1.12 | 0.60 | 0.84 | 0.42 |
| 18,000 | 1.00 | 0.50 | 0.75 | 0.37 |
| 20,000 | 0.90 | 0.45 | 0.68 | 0.34 |
| 22,000 | 0.81 | 0.40 | 0.61 | 0.30 |
| 24,000 | 0.75 | 0.37 | 0.56 | 0.28 |
| 26,000 | 0.69 | 0.34 | 0.52 | 0.26 |
| 28,000 | 0.64 | 0.32 | 0.48 | 0.24 |
| 30,000 | 0.60 | 0.30 | 0.45 | 0.23 |
| 32,000 | 0.56 | 0.28 | 0.42 | 0.21 |

[1] Based on a 50:50 ratio of females to males.

[2] Based on a 70:30 ratio of females to males.

[3] Sampling whole plants to obtain a reasonably accurate estimate of rootworm adult density in a field requires counts of beetles on two plants at 27 different sites within a field (total of 54 plants).

[4] Ear zone includes the ear, ear leaf, and one leaf above and one leaf below the ear. Sampling ear zones to obtain a reasonably accurate estimate of rootworm adult density in a field requires counts of beetles in five ear zones at 32 different sites within a field (total of 160 ear zones).

Rootworm-control products—If regular scouting in either soybean or corn during a growing season reveals that economic thresholds for corn rootworm adults were reached or exceeded, a rootworm-control product is warranted if corn is planted the following year. Following is a brief listing of the types of rootworm-control products. Discussion of the efficacy of these products follows the bulleted list.

- Granular and liquid soil insecticides labeled for control of corn rootworm larvae include Aztec 2.1%G and 4.67G (SmartBox application only), Capture 2EC, Counter CR, Empower, Force 3G, Fortress 2.5G and 5G (SmartBox application only), Furadan 4F, Lorsban 4E and 15G, Regent 4SC, and Thimet 20G.
- Insecticidal seed treatments labeled for control of corn rootworm larvae include Cruiser FS, Force ST with ProShield Technology, and Poncho 1250.
- Transgenic YieldGard Rootworm corn hybrids with the Bt Cry3Bb1 protein was registered for control of rootworm larvae in 2003.

Controlling rootworm adults to prevent them from laying eggs—This alternative for rootworm management requires diligent scouting. An insecticide to prevent rootworm adults from laying eggs in corn is warranted if the number of adults reaches or exceeds 0.75 per plant and 10% of the females are gravid (with eggs). A second application of an insecticide may be necessary if the number of adults reaches or exceeds 0.5 per plant. Controlling rootworm adults to prevent them from laying eggs is recommended only for corn planted after corn, not for corn planted after soybean. Research-based thresholds and precise timing of insecticide application for this management tactic for western corn rootworms in soybean have not been determined.

Insecticide efficacy trials conducted over several years by entomologists at the University of Illinois have revealed that the granular formulations of Aztec, Counter, Force, and Lorsban provided the most consistent root protection. The performance of the liquid insecticides has been less consistent in our research trials, although the performance of Capture 2EC has been more consistent than the performance of Regent 4SC. Regardless of the insecticide used, performance can be compromised by early planting, delayed larval hatch, the presence of large numbers of corn rootworm larvae, poor root regeneration abilities of the corn hybrid, and hot and dry soil conditions, especially in June and July.

The three insecticidal seed treatments labeled for control of corn rootworm larvae also have been evaluated in efficacy trials for several years. In general, when rootworm densities and root injury have been moderate, seed treatments have provided acceptable protection of the roots. However, when rootworm densities have been high and root injury has been moderately high to severe, insecticidal seed treatments have not provided consistently acceptable control of rootworm larvae.

The root protection afforded by the Bt protein in YieldGard Rootworm corn hybrids (event MON 863) has been excellent in university and company trials for several years. Rootworm-protected Bt corn hybrids have provided more consistent protection of corn roots against rootworm larval damage than insecticides and insecticidal seed treatments in research trials.

Results from 2003 University of Illinois efficacy trials for rootworm-control products are presented in Table 2. We conducted three rootworm control trials at outlying farms operated by the Department of Crop

Sciences: Northern Illinois Agronomy Research Center (Shabbona, near DeKalb); Northwestern Illinois Agricultural Research and Demonstration Center (near Monmouth); and Crop Sciences Research and Education Center (Urbana).

The root ratings in Table 2 are from the 1–6 scale, introduced by Hills and Peters (1971) at Iowa State University. The whole number root ratings are as follows:

1. no damage, or only a few minor feeding scars;
2. feeding scars evident, but no roots eaten off to within 1½ inches of the plant;
3. several roots eaten off to within 1½ inches of the plant, but never the equivalent of an entire node of roots destroyed;
4. one node (or the equivalent) of roots completely destroyed;
5. two nodes (or the equivalent) of roots completely destroyed;
6. three or more nodes (or the equivalent) of roots completely destroyed.

Most entomologists use a root rating of 3.0 to distinguish between acceptable root damage (<3.0) and less-than-acceptable root damage (≥ 3.0). However, the relationship between root ratings and yield may be altered depending on environmental conditions and corn hybrid (Gray and Steffey, 1998). For example, when corn plants are stressed by a lack of moisture, yield loss may result from plants with root ratings less than 3.0. On the other hand, when corn plants have plenty of moisture and the corn hybrid has the ability to compensate for rootworm injury, yield reductions may not occur even if plants have root ratings greater than 3.0. With this explanation of root ratings as background, you can place the performance of rootworm control products in our trials in 2003 in context.

The rootworm larval damage in all of the untreated checks at all three locations in 2003 resulted

**Table 2. Average root ratings from corn rootworm control trials in Illinois, 2003.**

| | | | Average root ratings[2] | | |
|---|---|---|---|---|---|
| **Product** | **Rate of application[1]** | **Placement** | **DeKalb** | **Monmouth** | **Urbana** |
| Aztec 2.1G | 6.7 oz | Band | 2.15bc | 2.70fgh | 2.10e–h |
| Aztec 4.67G[3] | 3.0 oz | Band | 2.10bc | 2.75fg | 2.15d–h |
| Aztec 4.67G[3] | 3.0 oz | Furrow | NA | 2.45gh | 2.30c–h |
| Capture 2EC[4] | 0.35 oz | Band | 2.70b | 3.20ef | 2.55c–g |
| Counter CR | 6 oz | Band | 2.45b | 2.20gh | 1.90h |
| Cruiser FS | — | Seed treatment | 3.50a | 4.20c | 2.70cde |
| Empower | 8.0 oz | Band | NA | 4.15c | 2.75cd |
| Empower | 8.0 oz | Furrow | NA | 4.01cd | 2.60c–f |
| Force 3G | 4.0 oz | Band | 2.20bc | 2.70fgh | 2.20d–h |
| Fortress 2.5G | 7.4 oz | Furrow | 2.20bc | 2.40gh | 2.00fgh |
| Fortress 5G[3] | 3.7 oz | Furrow | 2.50b | 2.45gh | 2.55c–g |
| Fortress 5G[3] | 4.5 oz | Furrow | 2.55b | NA | 1.95gh |
| Lorsban 15G | 8.0 oz | Band | 2.65b | 2.56fgh | 2.10e–h |
| Poncho 1250 (seed treatment) | — | — | 3.50a | 3.45de | 2.90c |
| MON 863 (DeKalbYieldGard Rootworm hybrid) | — | — | 1.45c | 2.05h | 1.35i |
| Untreated check (DeKalb hybrid) | — | — | 4.06a | 5.75a | 5.45a |
| Untreated check (NK hybrid) | — | — | 4.20a | 4.95b | 4.60b |

NA, product not applied in the trial.

Root ratings are from the 1–6 root-rating scale developed by Hills and Peters (1971).

[1] Rates of application are oz per 1,000 ft of row.

[2] Means followed by the same letter do not differ significantly according to Duncan's new multiple range test, $P = 0.05$.

[3] Aztec 4.67G and Fortress 5G were applied through the SmartBox closed handling system.

[4] Capture 2EC was applied at a volume of 5 gal/acre.

in root ratings greater than 4.0. Rootworm damage at our Monmouth and Urbana locations was particularly severe in the untreated checks. Two hybrids were included as untreated check plots in 2003—a DeKalb hybrid and a Northrup King (NK) hybrid. The four-row plots were to be harvested, so we included a nontransgenic DeKalb isoline to fairly compare yield with the MON 863 event in the DeKalb YieldGard Rootworm hybrid. At the time this report was written, yield data were not available.

Generally, rootworm control products performed very well in the three trials in 2003. All products held the average root rating to less than 3.0 at the Urbana site (planted on May 13), with severe damage in the untreated check. The rainfall pattern at the Urbana site apparently was beneficial for all products tested.

The rootworm larval damage at the Monmouth site (planted on May 16) was severe, and under the conditions at that site, most products performed well. However, the average root ratings for plots treated with Capture 2EC, Cruiser FS, Empower (a granular formulation of bifenthrin, the same active ingredient as in Capture), and Poncho 1250 were greater than 3.0. This site received less rainfall in June and July than the Urbana site.

The rootworm larval damage at the DeKalb site was less than at the other two sites, probably because rainfall prevented us from planting on a reasonable date. The trial at DeKalb was planted on May 28, right about the time when rootworm larvae were hatching. Consequently, all products except the seed treatments Cruiser FS and Poncho 1250 held the average root ratings to less than 3.0. In fact, the average root ratings in plots treated with Cruiser and Poncho were not significantly different from the average root ratings in the untreated check plots. It is possible that the active ingredients of Cruiser and Poncho did not have enough time to come off the seed and get into the soil to provide optimal control of rootworm larvae.

The MON 863 transgenic event for rootworm control provided excellent control of corn rootworms at all three sites, although it is worth noting that some root injury in the MON 863 plots at the

**Table 3 Results from the 2003 on-farm survey for rootworm larval damage in first-year corn, University of Illinois.**

| District or county | Mean root rating[1,2] | Standard deviation | Range of root ratings[1,2] | Percentage of plants with root ratings[1,2] ≥3.0 | Number of fields with mean root ratings[1,3] ≥3.0 |
|---|---|---|---|---|---|
| **Northwest** | | | | | |
| Bureau | 2.12 | 0.961 | 1.0–5.0 | 24 | 1 |
| Henry | 1.41 | 0.537 | 1.0–3.0 | 2 | 0 |
| Lee | 2.86 | 0.808 | 1.0–5.0 | 66 | 5 |
| Mercer | 1.68 | 0.513 | 1.0–3.0 | 2 | 0 |
| Ogle | 2.30 | 0.814 | 1.0–5.0 | 24 | 2 |
| **Northeast** | | | | | |
| DeKalb | 3.02 | 1.436 | 1.0–5.0 | 60 | 6 |
| Grundy | 2.08 | 0.853 | 1.0–4.0 | 32 | 2 |
| Kendall | 2.76 | 0.625 | 1.0–4.0 | 70 | 4 |
| LaSalle | 3.46 | 0.952 | 2.0–6.0 | 86 | 7 |
| Will | 1.96 | 0.947 | 1.0–6.0 | 12 | 1 |
| **West** | | | | | |
| Adams | 1.54 | 0.503 | 1.0–2.0 | 0 | 0 |
| Brown | 1.32 | 0.471 | 1.0–2.0 | 0 | 0 |
| Fulton | 1.29 | 0.456 | 1.0–2.0 | 0 | 0 |
| Hancock | 1.23 | 0.425 | 1.0–2.0 | 0 | 0 |
| Knox | 1.56 | 0.760 | 1.0–4.0 | 12 | 1 |
| McDonough | 1.64 | 0.525 | 1.0–3.0 | 2 | 0 |
| Schuyler | 1.26 | 0.443 | 1.0–2.0 | 0 | 0 |
| Warren | 1.24 | 0.431 | 1.0–2.0 | 0 | 0 |

*table continued on next page*

Monmouth site led to a root rating of 3.0 on individual roots. Because MON 863 is a low-to-moderate dose event, some rootworm larval injury on YieldGard Rootworm hybrids is to be expected.

## Variant Western Corn Rootworms That Lay Eggs in Soybean and Other Crops

Variant western corn rootworms continue to extend their range in Illinois. Sweep-net samples of western corn rootworm adults in soybean fields were taken by Joe Spencer and Eli Levine (Illinois Natural History Survey) and Scott Isard (Department of Geography) again in 2003. They have been sampling western corn rootworm adults in soybean for several years. The samples from 2003 revealed that western corn rootworms were found most frequently in soybean fields in east central, central, north central, and northeastern Illinois. The expansion of the range of variant western corn rootworms in Illinois in 2003 was most noticeable in northeastern counties and in counties south of Champaign County.

In 2002 and 2003, surveys of rootworm larval injury were conducted to track the distribution of the variant western corn rootworm that lays its eggs in crops other than corn. For the 36-county survey in 2003, we extracted five roots from each of 10 randomly selected fields within each preselected county. We had no knowledge whether an insecticide had been applied or a transgenic Bt hybrid had been planted in any of the fields surveyed. All 1,800 roots were transported to Urbana, washed, and rated using the Iowa State 1–6 root-rating scale (Hills and Peters, 1971).

Tables 3 and 4 show the root-rating information for each county included in the surveys in 2003 and 2002, respectively. Other maps, data, and additional information regarding the survey can be viewed at the "On-Farm Survey Results" page on the University of Illinois IPM Web site at http://www.ipm.uiuc.edu/wcrsurvey/index.html. County-specific information is

| District or county | Mean root rating[1,2] | Standard deviation | Range of root ratings[1,2] | Percentage of plants with root ratings[1,2] ≥3.0 | Number of fields with mean root ratings[1,3] ≥3.0 |
|---|---|---|---|---|---|
| **Central** | | | | | |
| Logan | 1.52 | 0.707 | 1.0–3.0 | 12 | 0 |
| Macon | 2.44 | 1.053 | 1.0–6.0 | 30 | 2 |
| Marshall | 2.66 | 0.772 | 2.0–5.0 | 50 | 2 |
| Mason | 1.64 | 0.525 | 1.0–3.0 | 8 | 0 |
| McLean | 2.62 | 0.725 | 1.0–5.0 | 54 | 2 |
| Peoria | 1.78 | 0.679 | 1.0–4.0 | 10 | 0 |
| Stark | 2.12 | 0.689 | 1.0–4.0 | 26 | 0 |
| Tazewell | 1.88 | 0.666 | 1.0–4.0 | 10 | 0 |
| Woodford | 2.98 | 0.979 | 2.0–6.0 | 66 | 5 |
| **East** | | | | | |
| Champaign | 2.60 | 0.535 | 2.0–4.0 | 68 | 2 |
| Ford | 2.32 | 0.868 | 1.0–4.0 | 46 | 2 |
| Iroquois | 2.46 | 0.973 | 1.0–5.0 | 30 | 2 |
| Kankakee | 1.76 | 0.716 | 1.0–3.0 | 16 | 0 |
| Livingston | 2.40 | 0.990 | 1.0–5.0 | 28 | 1 |
| Vermilion | 2.10 | 0.735 | 1.0–4.0 | 28 | 0 |
| **West southwest** | | | | | |
| Christian | 1.62 | 0.490 | 1.0–2.0 | 0 | 0 |
| Pike | 1.42 | 0.499 | 1.0–2.0 | 0 | 0 |
| Sangamon | 2.06 | 0.512 | 1.0–3.0 | 16 | 0 |

[1] Root ratings are from the 1-to-6 root-rating scale developed by Hills and Peters (1971).

[2] $n$ = 50 roots (5 roots per field, 10 fields per county).

[3] Total of 10 fields sampled per county.

**Table 4 Results from the 2002 on-farm survey for rootworm larval damage in first-year corn, University of Illinois.**

| District or county | Mean root rating[1,2] | Standard deviation | Range of root ratings[1,2] | Percentage of plants with root ratings[1,2] ≥3.0 | Number of fields with mean root ratings[1,3] ≥3.0 |
|---|---|---|---|---|---|
| **Northwest** | | | | | |
| Lee | 2.0 | 0.51 | 1.0–3.0 | 14 | 0 |
| Mercer | 1.7 | 0.44 | 1.0–2.0 | 0 | 0 |
| **Northeast** | | | | | |
| DeKalb | 2.0 | 0.35 | 1.0–3.0 | 6 | 0 |
| Grundy | 2.5 | 1.03 | 1.0–5.0 | 35 | 2 |
| LaSalle | 3.1 | 1.12 | 2.0–6.0 | 66 | 4 |
| Will | 2.2 | 0.61 | 1.0–4.0 | 20 | 1 |
| **West** | | | | | |
| Adams | 1.3 | 0.46 | 1.0–2.0 | 0 | 0 |
| Brown | 1.1 | 0.30 | 1.0–2.0 | 0 | 0 |
| Fulton | 1.5 | 0.51 | 1.0–2.0 | 0 | 0 |
| Hancock | 1.7 | 0.47 | 1.0–2.0 | 0 | 0 |
| Knox | 1.8 | 0.37 | 1.0–2.0 | 0 | 0 |
| McDonough | 1.1 | 0.27 | 1.0–2.0 | 0 | 0 |
| Schuyler | 1.5 | 0.51 | 1.0–2.0 | 0 | 0 |
| Warren | 1.9 | 0.30 | 1.0–2.0 | 0 | 0 |
| **Central** | | | | | |
| Logan | 1.8 | 0.45 | 1.0–3.0 | 2 | 0 |
| Macon | 2.2 | 0.81 | 1.0–4.0 | 32 | 0 |
| Marshall | 1.9 | 0.85 | 1.0–5.0 | 10 | 1 |
| Mason | 1.3 | 0.51 | 1.0–3.0 | 2 | 0 |
| McLean | 2.6 | 0.76 | 1.0–5.0 | 53 | 3 |
| Peoria | 1.4 | 0.53 | 1.0–3.0 | 2 | 0 |
| Stark | 1.5 | 0.50 | 1.0–2.0 | 0 | 0 |
| Tazewell | 1.5 | 0.61 | 1.0–3.0 | 6 | 0 |
| Woodford | 2.0 | 0.19 | 2.0–3.0 | 4 | 0 |
| **East** | | | | | |
| Champaign | 1.9 | 0.44 | 1.0–3.0 | 4 | 0 |
| Ford | 2.5 | 0.86 | 2.0–5.0 | 30 | 1 |
| Iroquois | 1.9 | 0.85 | 1.0–5.0 | 16 | 1 |
| Kankakee | 1.9 | 0.56 | 1.0–3.0 | 11 | 0 |
| Livingston | 2.3 | 0.78 | 1.0–5.0 | 22 | 1 |
| Vermilion | 2.1 | 0.45 | 1.0–4.0 | 9 | 0 |
| **West southwest** | | | | | |
| Christian | 1.9 | 0.35 | 1.0–2.0 | 0 | 0 |
| Pike | 1.7 | 0.47 | 1.0–2.0 | 0 | 0 |
| Sangamon | 1.7 | 0.44 | 1.0–2.0 | 0 | 0 |

[1] Root ratings are from the 1-to-6 root-rating scale developed by Hills and Peters (1971).

[2] $n$ = 50 roots (5 roots per field, 10 fields per county).

[3] Total of 10 fields sampled per county.

featured at this site, including the relative location of each field within a county and the corresponding root ratings from that field.

Overall, results from the survey in 2003 revealed that the distribution of the variant western corn rootworm has spread farther northwest than was detected in 2002. The most severe rootworm larval damage in 2003 occurred east of a line extending northeast from Woodford County through DeKalb County. However, average root ratings in Lee, Marshall, and Stark counties were greater in 2003 than they were in 2002. Although Bureau and Ogle counties were not surveyed for rootworm larval damage in 2002, the average root ratings in these counties in 2003 were similar to the average root ratings in Lee, Marshall, and Stark counties.

The variant western corn rootworm still does not seem to be present in most counties west of the Illinois River. Average root ratings in Adams, Brown, and McDonough counties in 2003 were similar to average root ratings from similar surveys in these same counties in the mid- to late 1980s (Steffey et al., 1992).

If producers in northwestern Illinois have not already begun to monitor for western corn rootworm adults in soybean fields, they should initiate monitoring in 2004. Guidelines for using yellow sticky traps to monitor for western corn rootworms in soybean can be found on the University of Illinois IPM Web site. Results from western corn rootworm monitoring efforts should allow growers to determine the best management strategy for each field. Producers within counties in which severe rootworm larval damage has been detected for some time should continue efforts to determine whether western corn rootworm densities in soybean indicate that control of larvae in corn the following year is necessary. Economic levels of rootworm larvae do not occur in every field.

## References


Gray ME and Steffey KL. 1998. Corn rootworm (Coleoptera: Chrysomelidae) larval injury and root compensation of 12 maize hybrids: an assessment of the economic injury index. *Journal of Economic Entomology* 91:723–740.

Hills TM and Peters DC. 1971. A method of evaluating post-planting insecticide treatments for control of western corn rootworm larvae. *Journal of Economic Entomology* 64:764–765.

Krysan JL, Foster DE, Branson TF, Ostlie KR, and Cranshaw WS. 1986. Two years before the hatch: rootworms adapt to crop rotation. *Bulletin of the Entomological Society of America* 32:250–253.

Levine E, Spencer JL, Isard SA, Onstad DW, and Gray ME. 2002. Adaptation of the western corn rootworm to crop rotation: evolution of a new strain in response to a management practice. *American Entomologist* 48:94–107.

Steffey KL, Gray ME, and Kuhlman DE. 1992. Extent of corn rootworm larval damage in corn after soybeans: search for the expression of the prolonged diapause trait in Illinois. *Journal of Economic Entomology* 85:268–275.

Wright R, Meinke L, and Jarvi K. 1999. Corn rootworm management. Nebraska Cooperative Extension EC-99-1563. University of Nebraska, Lincoln.

# Notes

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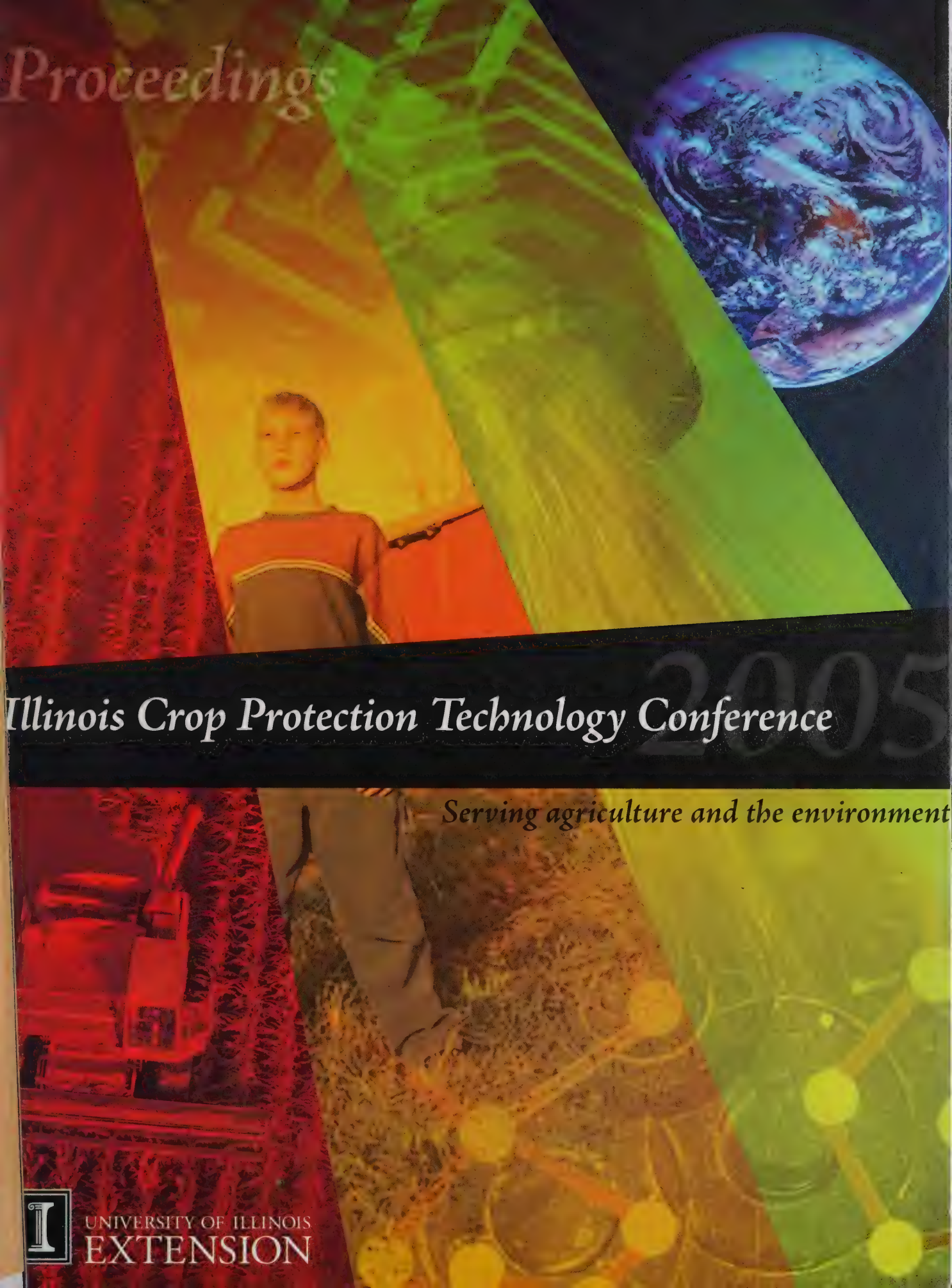
Proceedings
2005
Illinois Crop Protection Technology Conference
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# Illinois Crop Protection Technology Conference

*Serving agriculture and the environment*

# *Proceedings*

**January 5 & 6**

UNIVERSITY OF ILLINOIS
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College of Agricultural, Consumer and Environmental Sciences

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# *Program: January 5 & 6, 2005*

## WEDNESDAY MORNING, JANUARY 5

| | |
|---|---|
| 9:00 AM | **Welcome and Opening Remarks** • Illini Rooms A, B, C • *Mike Gray and Suzanne Bissonnette* |

**Keynote Session: Global Issues: Local Impact** (2 CCA credits in Crop Management) *Todd Gleason, Moderator*

| | |
|---|---|
| 9:10 AM | Predicting Climatological Change in the Great Lakes Region: The Reality of the Issue • *Donald J. Wuebbles* |
| 9:40 AM | Climatological Changes: Implications for Agriculture • *Steven Hollinger* |
| 10:10–10:30 AM | Break, South Lounge |
| 10:30 AM | Elevated Ozone and Carbon Dioxide: Implications for Agriculture • *Stephen Long* |
| 11:00 AM | Influence of Elevated Ozone and Carbon Dioxide on Insect Densities • *Evan DeLucia* |
| 11:30 AM | Panel Discussion |
| 11:50 AM–1:00 PM | Lunch, on your own |

## WEDNESDAY AFTERNOON, JANUARY 5

***Symposia A and B run concurrently with Specialized Sessions 1–5 from 1:00–2:30 PM***

**Symposium A: Asian Soybean Rust: Outlook for 2005** • Illini Room A (1.5 CCA credits in Integrated Pest Management) *Terry Niblack and Dean Malvick, Moderators*

| | |
|---|---|
| 1:00 PM | Historical View Point and Soybean Resistance to Soybean Rust • *Glen Hartman* |
| 1:25 PM | Models and Dispersal for Asian Soybean Rust • *Roger Magary* |
| 1:50 PM | Management of Asian Soybean Rust • *Monte Miles* |
| 2:15 PM | Panel Discussion |

**Symposium B: Western Corn Rootworms: A Season to Forget or Remember?** • Illini Room B (1.5 CCA credits in Integrated Pest Management) *Robert Bellm and Mike Hellmer, Moderators*

| | |
|---|---|
| 1:00 PM | Movement of Variant Western Corn Rootworm Adults Among and Between Fields • *Joe Spencer* |
| 1:15 PM | Insecticidal Seed Treatments and Soil Insecticides for Corn Rootworm Control • *Kevin Steffey* |
| 1:30 PM | Transgenic YieldGard Rootworm Hybrid Stumbles in Urbana Experiment: Why? • *Mike Gray* |
| 1:45 PM | Update on the Range Expansion of the Variant Western Corn Rootworm in Indiana and Illinois • *John Obermeyer and Jared Schroeder* |
| 2:05 PM | Panel Discussion |

## *Specialized Sessions*

**1. Aquatic Weed Management** • Room 407 • *Carole Lembi and George Czapar*

This session will focus on the identification and management of aquatic plants with an emphasis on chemical and biological control, use of barley straw and other management methods. (1.5 CCA credits in Integrated Pest Management)

**2. On-Farm Research: If I Like the Results, It Must Be Real Science** • Room 315B • *Emerson Nafziger*

Many producers do some comparisons of management practices in their fields. Companies do this as well, often in a little different way and for different reasons. This workshop will address why and how on-farm research can (or maybe cannot) answer real-life questions, and what to do if we don't like or don't trust the answers such trials produce. We will go through some examples, including analysis of data and how to draw conclusions. (1.5 CCA credits in Crop Production)

**3. Alfalfa Production Management-Steps to Greater Profits** • Room C • *Dave Feltes, Bob Hoeft, and Jim Morrison*

Producing high yielding, high quality alfalfa is the foundation for commercial hay producers and for profitable livestock operations. This seminar will focus on soil fertility and fertilization, insect pest management, and other agronomic production practices that result in a thick, vigorous, productive stand including forecast tools to predict the timely harvest of alfalfa. (1.5 CCA credits in Crop Production)

**4. The Quality of Soil Testing: Expectations, Perceptions, and Reality** • Room 314A • *Robert O. Miller*

Soil testing is a fundamental component of making sound nutrient recommendations. Be it the farmer/owner or the consultant, they have high expectations for a fast turn-around time and low cost. With the advent of grid sampling and NRCS 590 nutrient management plans there is increasing importance assigned to the quality of the laboratory analysis. This session will evaluate the issues of client perceptions, the quality of soil testing, and the cost of service with respect to nutrient management. (1.5 CCA credits in Nutrient Management)

**5. The Importance of Spray Droplet Size for Ground and Aerial Applications** • Room 404 • *Scott Bretthauer*

The size of spray droplets created during both ground and aerial applications plays a major role in determining the success of the application. Droplet size affects coverage of the target and thus influences the efficacy of the treatment. Droplet size also is a determinant in the risk of drift occurring. These issues will be discussed in this session as well as different techniques and equipment that aerial and ground applicators utilize to control droplet size during an application. (1.5 CCA credits in Integrated Pest Management)

2:30–3:00 PM Break, South Lounge and Room 406

***Symposia A and B and Specialized Sessions 1–5 repeated concurrently from 3:00–4:30 PM***

**Symposium A (repeated): Asian Soybean Rust: Outlook for 2005** • Illini Room A

**Symposium B (repeated): Western Corn Rootworms: A Season to Forget or Remember?** • Illini Room B

**Specialized Session 1 (repeated): Aquatic Weed Management** • Room 407

**Specialized Session 2 (repeated): On-Farm Research: If I Like the Results, It Must Be Real Science** • Room 315B

**Specialized Session 3 (repeated): Alfalfa Production Management—Steps to Greater Profits** • Room C

**Specialized Session 4 (repeated): The Quality of Soil Testing: Expectations, Perceptions, and Reality** • Room 314A

**Specialized Session 5 (repeated): The Importance of Spray Droplet Size for Ground and Aerial Applications** • Room 404

4:30–6:30 PM IFCA-Sponsored Mixer
Illini Union Ballroom, 2nd floor

This mixer is sponsored by the Illinois Fertilizer and Chemical Association. It is intended for everyone to meet with speakers, sponsors, and committee members in an informal atmosphere.

## THURSDAY MORNING, JANUARY 6

***Symposia C and D run concurrently with Specialized Sessions 6–10 from 8:00–9:30 AM***

**Symposium C: Disease Management Through Foliar Fungicide Application** • Illini Room A (1.5 CCA credits in Integrated Pest Management) *Matt Montgomery and Mike McKeague, Moderators*

8:00 AM Management of Soybean Foliar Diseases With Fungicides • *Don Hershman*

8:25 AM Do Foliar Fungicides Have a Place in Corn Production? • *Gregory Shaner*

8:50 AM Management of Wheat Diseases With Fungicides • *Don Hershman*

9:15 AM Question & Answer Session

**Symposium D: Transgenic Issues** • Illini Room B (1.5 CCA credits in Integrated Pest Management) *Bob Starke and Aaron Hager, Moderators*

8:00 AM Delivering on the Biotech Promise Today and the not so Distant Future • *Tom West*

8:25 AM The Future of Insect Resistance Management: Balancing Ecology, Evolution and Economics to Determine Best Management Practices • *Charles Guse*

8:50 AM Glyphosate-Resistant Weeds in Illinois: Way Down the Road or Right Around the Corner? • *Patrick Tranel*

9:15 AM Panel Discussion

## *Specialized Sessions*

**6. Cyberfarm 2005** • Room 404 • *Dennis Bowman and Joe Curless*

By 2005, all Illinois County FSA Offices will be using Geographic Information Systems (GIS) in place of aerial photography. In this session you will learn about this new method and how you can take advantage of this information. (1.5 CCA credits in Crop Production)

**7. Asian Soybean Rust: Sampling Protocol, Thresholds & Scouting** • Room 314A • *Suzanne Bissonnette*

This session will cover the nitty gritty of how to actually scout for soybean rust, how to take a sample, what to do with it, and why. We will also approach the topic of what protocols to follow once the disease is confirmed in the continental United States. (1.5 CCA credits in Integrated Pest Management)

**8. The Influence of Soil Physical and Chemical Properties on Herbicide Availability and Degradation** • Room C • *Bill Simmons*

Soil-applied herbicides continue to be an important component of weed management programs. Soil properties, such as pH, texture, and organic matter content, have a significant influence on herbicide availability, degradation, and persistence. This session will focus on how herbicides in the soil environment are influenced by various soil physical and chemical properties. (1.5 CCA credits in Soil and Water)

**9. Soybean Aphid Management Update: What to Select From a Variety of Pest Management Tools** • Ballroom • *Matthew O'Neal*

Soybean aphid infestations in 2004 were far below 2003 levels. Will 2005 present significant management challenges due to this new insect pest of soybeans? What are the key biological and environmental factors that regulate densities of this insect? Management advice and thresholds for this insect will be provided. (1.5 CCA credits in Integrated Pest Management)

**10. Injury Across the Landscape: When Herbicide Applications go Awry** • Room 407 • *Dawn Nordby and Michelle Wiesbrook*

Herbicides sometimes move or drift from the target area and cause damage to non-target plants. This presentation will provide information on identifying injury symptoms on various vegetable crops, annual and herbaceous perennial ornamental species, trees, and shrubs that herbicides may injure. Participants will also learn the basics of how herbicides work and apply this information toward identifying the injury symptoms caused by various herbicide families. (1.5 CCA credits in Integrated Pest Management)

| | |
|---|---|
| 9:30–10:00 AM | Break, South Lounge and Room 406 |

***Symposia C and D and Specialized Sessions 6–10 repeated concurrently from 10:00–11:30 AM***

**Symposium C (repeated): Disease Management Through Foliar Fungicide Application** • Illini Room A

**Symposium D (repeated): Transgenic Issues** • Illini Room B

**Specialized Session 6 (repeated): Cyberfarm 2005** • Room 404

**Specialized Session 7 (repeated): Asian Soybean Rust: Sampling Protocol, Thresholds & Scouting** • Room 314A

**Specialized Session 8 (repeated): The Influence of Soil Physical and Chemical Properties on Herbicide Availability and Degradation** • Room C

**Specialized Session 9 (repeated): Soybean Aphid Management Update: What to Select From a Variety of Pest Management Tools** • Ballroom

**Specialized Session 10 (repeated): Injury Across the Landscape: When Herbicide Applications go Awry** • Room 407

| | |
|---|---|
| 11:30 AM–1:00 PM | Lunch, on your own |

## THURSDAY AFTERNOON, JANUARY 6

***Symposia E and F run concurrently with Specialized Sessions 11–15 from 1:00–2:30 PM***

**Symposium E: Emerging Crop Production and Protection Issues** • Illini Room A (1 CCA credit in Integrated Pest Management and 0.5 CCA credit in Crop Production) *Dawn Nordby and Jean Trobec, Moderators*

| | |
|---|---|
| 1:00 PM | Where is the IPM in Treating Soybeans With a Fungicide/Insecticide Combination in the Absence of Pests? • *Doug Johnson* |
| 1:20 PM | How Early is Too Early to Plant? • *Emerson Nafziger* |
| 1:40 PM | Western Bean Cutworm: Lessons Learned from Iowa, Expectations for Illinois • *Marlin Rice* |
| 2:00 PM | Robotics in Agriculture: Asimov Meets Corn • *Tony Grift* |
| 2:20 PM | Panel Discussion |

**Symposium F: Regulatory Issues & Resource Management** • Illini Room B (1.5 CCA credits in Soil and Water) *Dan Anderson and Gerald Kirbach, Moderators*

| | |
|---|---|
| 1:00 PM | Whatever Happened to the Pesticides in the Groundwater Management Plan? • *Warren Goetsch* |
| 1:20 PM | Developing Nutrient Standards in Illinois • *George Czapar* |
| 1:40 PM | Soil and Water Quality for Conservation Security Program • *David Brandt* |
| 2:00 PM | Economic Benefits of Conservation Drainage • *Richard Cooke* |
| 2:20 PM | Panel Discussion |

## *Specialized Sessions*

**11. Troubleshooting Pest Management Challenges in Field Crops** • Room 314A • *Robert Bellm, David Feltes, and Matt Montgomery*

Troubleshooting pest management problems in producers' fields requires a thorough knowledge of insects, weeds, and diseases. Instructors will present some practical troubleshooting challenges to the participants. Active discussion will be encouraged. (1.5 CCA credits in Integrated Pest Management)

**12. Fungicide Basics for Field Crops** • Room 404 • *Bruce Paulsrud and Dean Malvick*

Fungicides are not widely used in most Illinois field crops, but they are an important disease management tactic and may become more important in some challenging disease management situations. We'll help you understand the limitations of fungicides, what they do and how they work, reasons they may fail, how you might enhance their performance, and how to avoid the development of fungicide-resistant fungal populations. In addition, if you want to become more familiar with terms such as preventive, curative, acropetal systemic, fungistatic, cross-resistance, and FRAC Group, then this is the specialized session for you. (1.5 CCA credits in Integrated Pest Management)

**13. Secondary Insect Management** • Room C • *Kevin Black and Murdick McLeod*

This session will provide a detailed look at the management of secondary insect pests such as white grubs, wireworms, and grape colaspis. Effectiveness of insecticidal seed treatments on these pests also will be discussed. (1.5 CCA credits in Integrated Pest Management)

**14. Wheat Management for the 21st Century: Updating the Old, Introducing the New** • Ballroom • *Eric Adee and Steve Ebelhar*

As with any crop, there are always new data being gathered that can help improve the management of wheat. This information is either updating previous recommendations or introducing new aspects of wheat management. The topics covered will take wheat from the fall planning and planting, through the spring management decisions, and onto harvest. (1.5 CCA credits in Crop Production)

**15. Corn Nematodes: The Hidden Enemies** • Room 407 • *Terry Niblack*

Corn-parasitic nematodes used to be a problem in Midwestern corn production, but it has been decades since anyone except bottomland corn farmers thought about them much. Why are nematodes becoming a problem in corn production now? Is there a "corn cyst nematode?" These questions and others will be answered in this session, including what we currently know about the four major corn nematode groups, how to scout for them, and what to do about them if a problem is found. (1.5 CCA credits in Integrated Pest Management)

2:30–3:00 PM Break, South Lounge and Room 406

***Symposia E and F and Specialized Sessions 11–15 repeated concurrently from 3:00–4:30 PM***

**Symposium E (repeated): Emerging Crop Production and Protection Issues** • Illini Room A

**Symposium F (repeated): Regulatory Issues & Resource Management** • Illini Room B

**Specialized Session 11 (repeated): Troubleshooting Pest Management Challenges in Field Crops** • Room 314A

**Specialized Session 12 (repeated): Fungicide Basics for Field Crops** • Room 404

**Specialized Session 13 (repeated): Secondary Insect Management** • Room C

**Specialized Session 14 (repeated): Wheat Management for the 21st Century: Updating the Old, Introducing the New** • Ballroom

**Specialized Session 15 (repeated): Corn Nematodes: The Hidden Enemies** • Room 407

4:30 PM Adjourn

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# Predicting Climatological Change in the Great Lakes Region: The Reality of the Issue

*Donald J. Wuebbles and Katharine Hayhoe*

*This article is an update on the findings of our previous studies (Wuebbles and Jain, 2002; Wuebbles and Hayhoe, 2004) and various literature updates since the last international evaluation of the science of climate change carried out by hundreds of scientists for the Intergovernmental Panel on Climate Change (IPCC 2001).*

Climate is defined as the typical behavior of the atmosphere, the aggregation of the weather, and is generally expressed in terms of averages and variances of temperature, precipitation, and other physical properties. The greenhouse effect, the ability of certain gases such as carbon dioxide and water vapor to effectively trap some of the reemission of solar energy by the planet, is a necessary component to life on Earth; without the greenhouse effect the planet would be too cold to support life. However, human activities are increasing the concentration of carbon dioxide and several other greenhouse gases, plus changing the atmospheric concentrations of atmospheric particles that also have radiatively important effects in the Earth's atmosphere. Recent increases in global averaged temperature over the past two decades already seem to be outside the normal variability of temperature changes for the past thousand years. A number of different analyses strongly suggest that this temperature increase is resulting from the net effects of increasing atmospheric concentrations of greenhouse gases and particles, thus lending credence to the concerns about much larger changes in climate being predicted for the coming decades. In the absence of major emission control policies, current economic and technological projections suggest that these concentrations will continue to increase well into the future, implying much larger changes in climate over the coming decades than what has already been seen. The term "global warming" is often used in the press, but scientists use the term "climate change," because it more adequately represents the complex changes in climate that are occurring.

Although climate change is a global issue, its impacts will be seen and felt most strongly at the regional and local level. The United States and much of our planet already face concerns over a variety of issues, including water quality and availability, pollution, ecosystem health, and expanding urbanization. Exacerbating these concerns is the possibility of long-term changes in climate, including rising temperatures, changing rainfall patterns, increasing sea levels, and greater frequency of extreme events such as droughts or floods. These changes carry the potential for widespread impacts on natural resources, ecological systems, human health, infrastructure, and economic systems. To successfully address these concerns and impacts, regional and national policy development and planning focused on mitigation and adaptation to existing stresses must include the uncertainties introduced by future climate change. Climate change is clearly one of the biggest issues facing humanity in the twenty-first century. The objective of this article is to discuss the vulnerability and risks to humanity and ecosystems associated with climate change within the context of current understanding of the science of climate change and possible impacts.

## The Changing Climate

There is an extensive amount of evidence indicating that the Earth's climate has warmed during the past century. Foremost among this evidence are compilations of the variation in global mean sea surface temperature and in surface air temperature over land and sea. Supplementing these indicators of surface temperature change is a global network of balloon-based atmospheric temperature since 1958. As well, there are several indirect or proxy indications of temperature change, including satellite observations (since 1979) of microwave emissions from the atmosphere, and records of the width and density of tree rings. The combination of surface-, balloon-, and satellite-based indicators provides a more complete picture than could be obtained from any given indicator alone, whereas proxy records from tree rings and other indicators allow the temperature record at selected locations to be extended back for a thousand years. Apart from temperature, changes in the extent of alpine glaciers, sea ice, seasonal snow cover, and the length

of the growing season have been documented that are consistent with the evidence that the climate is warming. Less certain, but also consistent, changes seem to have occurred in precipitation, cloudiness, and interannual temperature and rainfall variability.

Thermometer-based measurements of air temperature have been systematically recorded at a number of sites in Europe and North America as far back as 1760. However, the set of observing sites did not attain sufficient geographic coverage to permit a rough computation of the global average land temperature until the mid-nineteenth century. Land-based, marine, air, and sea surface temperature data sets all require rather involved corrections to account for changing conditions and measurement techniques. Analyses of these records indicates a global mean warming from 1861 to 2000 of about 0.6 ± 0.2°C.

The increase in temperature has occurred in two distinct periods. The first occurred from roughly 1910–1945, whereas the second is since 1976. Recent warming has been about 0.2°C per decade. In terms of global mean annual temperature, the 1990s was the warmest decade on record, whereas 1998 was the warmest year since 1861, the beginning of the instrumental record (2002 is the second warmest and 2001 the third warmest). The year 1998 was also one of the warmest years on record throughout much of the U.S. Midwest.

In addition to limited sampling of temperature with altitude through balloon-borne instruments, satellite-based sensors, known as microwave sounding units (MSUs), are being used to examine global temperature changes in the middle troposphere (mainly the 850–300 HPa layer) and in the lower stratosphere (~50–100 HPa). None of the channels sample at the ground. The MSU measurements have been controversial because some earlier versions of the satellite data set had indicated a cooling in the lower troposphere in contrast to the warming from the ground-based instruments. However, a number of errors and problems (e.g., due to decay in the orbit of the satellite and misinterpretation of the stratospheric effects on the signal) with the MSU data have been found, and the latest analyses of MSU corrected for these problems show a warming in general agreement with that found at the ground. These analyses also suggest that the cooling effect of decreasing ozone in the lower stratosphere (as a result of chlorine and bromine from human-related emissions of chlorofluorocarbons and other halocarbons) may have led to part of the difference in upper tropospheric and ground-level temperature trends.

The 1910–1945 warming primarily occurred in the northern Atlantic. In contrast, the most recent warming has primarily occurred at middle and high latitudes of the Northern Hemisphere continents in winter and spring, whereas the northwestern portion of the northern Atlantic and the central North Pacific oceans have shown year-around cooling. Significant regional cooling occurred in the Northern Hemisphere during the period from 1946 to 1975.

Proxy temperature indicators, such as tree ring width and density, the chemical composition and annual growth rate in corals, and characteristics of annual layers in ice cores, are being used at a number of locations to extend temperature records back as much as 2000 years. The reconstruction indicates the decade of the 1990s has been warmer than at any time during this millennium. A number of different analyses have been done of temperature changes over the past millennium, including several based on underground temperature measurements from boreholes. Except for a few analyses that have been heavily criticized for not being scientifically accurate, these analyses have all reached the same basic conclusion, that the late twentieth century warming is unprecedented in the past 500 to 1000 years. The latest analysis going back 2000 years seems to further substantiate these findings.

Recent studies with state-of-the-art numerical models of the climate system have been able to match the observed temperature record well but only if they include the effects of greenhouse gases and aerosols (a yet unpublished analysis by National Center for Atmospheric Research scientists shows excellent comparison over the past millennium). These studies indicate that natural variability of the climate system and solar variations are not sufficient to explain the increasing temperatures in the 1980s and 1990s. However, natural variability and variations in the solar flux are important in fully explaining the increase in temperature in the 1910–1945 period. Emissions from large volcanic eruptions resulting in sulfate aerosols and other aerosols in the lower stratosphere are also important in explaining some of the short-term variations in the climate record.

## Human Factors in Climate Change

Without human intervention, concentrations of many atmospheric gases would be expected to change slowly. Ice core measurements of the gases trapped in ancient ice bubbles indicate this was the case before the last century. However, since the beginning of the industrial age, emissions associated with human activities have risen rapidly. Agriculture, industry, waste disposal, deforestation, and especially fossil fuel use have been producing increasing amounts of carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), chlorofluorocarbons (CFCs), and other important gases. Due to increasing emissions, atmospheric levels of these greenhouse gases have been building at an unprecedented rate, raising concerns regarding the impact of these gases on climate. Some of the gases, such as CFCs,

are also responsible for large observed depletions in the natural levels of another gas important to climate, ozone. Of these gases, two, carbon dioxide and methane, are of special concern to climate change. These two gases are discussed in some detail in the sections below. Under the international Montreal Protocol, emissions of CFCs and other halocarbons are being controlled, and their atmospheric concentrations will gradually decline over the next century. Emissions leading to atmospheric concentrations of sulfate and other aerosol particles are also important to climate change and are further discussed below. Unless stated otherwise, most of the discussion below is based on the most recent IPCC and World Meteorological Organization international assessments of global change, with concentrations and trends updated as much as possible, particularly from data available from National Oceanic and Atmospheric Administration's Climate Monitoring and Diagnostics Laboratory.

Carbon dioxide has the largest changing concentration of the greenhouse gases. It is also the gas of most concern to analyses of potential human effects on climate. Accurate measurements of atmospheric $CO_2$ concentration began in 1958. The annually averaged concentration of $CO_2$ in the atmosphere has risen from 316 ppm (molar) in 1959 to >370 ppm currently. The $CO_2$ measurements exhibit a seasonal cycle, which is mainly caused by the seasonal uptake and release of atmospheric $CO_2$ by terrestrial ecosystems. The average annual rate of increase over the whole time period is ~1.2 ppm or 0.4%/year, with the rate of increase over the past decade being ~1.6 ppm/year. Measurements of $CO_2$ concentration in air trapped in ice cores indicate that the preindustrial concentration of $CO_2$ was ~280 ppm. These data indicate that carbon dioxide concentrations fluctuated by ±10 ppm around 280 ppm for over a thousand years until the recent increase to the current 370+ ppm, an increase of [mt]30%.

Why has the atmospheric concentration of $CO_2$ increased so dramatically? Analyses with models of the atmosphere–ocean–biosphere system of the carbon cycle, in coordination with observational analyses of the isotopes of carbon in $CO_2$, indicate that human activities are primarily responsible for the increase in $CO_2$. Two types of human activities are primarily responsible for emissions of $CO_2$: fossil fuel use, which released ~6.0 GtC into the atmosphere in 1990, and land use, including deforestation and biomass burning, which may have contributed about 1.6 ± 1.0 GtC in addition to that from fossil fuels. Evaluations of carbon releases from vegetation and soils based on changes in land use indicate that land use decreased carbon storage in vegetation and soil by ~170 Gt since 1800. The added atmospheric $CO_2$ resulting from human activities is redistributed within the atmospheric, oceanic, and biospheric parts of the global carbon cycle, with the dynamics of this redistribution determining the corresponding rise in atmospheric $CO_2$ concentration. In the future, as the amount of $CO_2$ increases in the atmosphere and in the ocean, it is expected that the oceans will take up a smaller percentage of the new emissions. Analyses of the carbon budget previously had implied that a mismatch existed between observed levels of $CO_2$ and known loss processes. This discrepancy suggested that a missing carbon sink has existed during recent decades. This sink now seems to be largely explained through increased net carbon storage by the terrestrial biomass stimulated by the $CO_2$ fertilization effect (increased growth in a higher $CO_2$ concentration atmosphere).

Carbon dioxide is emitted when carbon-containing fossil fuels are oxidized by combustion. Carbon dioxide emissions depend on energy and carbon content, which ranges from 13.6 to 14.0 MtC/EJ for natural gas, from 19.0 to 20.3 MtC/EJ for oil, and from 23.9 to 24.5 MtC/EJ for coal. Other energy sources such as hydro, nuclear, wind, and solar have no direct carbon emissions. Biomass energy, however, is a special case. When biomass is used as a fuel, it releases carbon with a carbon-to-energy ratio similar to that of coal. However, the biomass has already absorbed an equal amount of carbon from the atmosphere before its emission, so that net emissions of carbon from biomass fuels are zero over its life cycle.

Human-related emissions from fossil fuel use have been estimated as far back as 1751. Before 1863, emissions did not exceed 0.1 GtC/year. However, by 1995 they had reached 6.5 GtC/year, giving an average emission growth rate slightly greater than 3% per year over the past two and a half centuries. Recent growth rates have been significantly lower, at 1.8%/year between 1970 and 1995. Emissions were initially dominated by coal. Since 1985, liquids have been the main source of emissions despite their lower carbon intensity. The regional pattern of emissions also has changed. Once dominated by Europe and North America, developing nations are providing an increasing share of emissions. The United States still accounts for roughly 20% of the global emissions.

Future $CO_2$ levels in the atmosphere depend not only on the assumed emission scenarios but also on the transfer processes between the major carbon reservoirs, such as the oceans (with marine biota and sediments) and the terrestrial ecosystems (with land use changes and soil and forest destruction. Recent work for the new IPCC assessment show, based on projections of fossil-fuel use and land use changes, that the concentration of $CO_2$ are expected to increase well above current levels by 2100 (75 to 220% over preindustrial concentrations). As discussed below, none of these scenarios leads to stabilization of the $CO_2$ concentration before 2100.

Although its atmospheric abundance is <0.5% that of $CO_2$, on a molecule by molecule basis, a molecule of $CH_4$ is ~50 times more effective as a greenhouse gas in the current atmosphere than $CO_2$. When this is combined with the large increase in its atmospheric concentration, methane becomes the second most important greenhouse gas of concern to climate change. Based on analyses of ice cores, the concentration of methane has more than doubled since preindustrial times, from a globally averaged atmospheric concentration of methane of 0.7 ppm to now being about 1.80 ppm.

Methane emissions come from a number of different sources, both natural and anthropogenic. One type of human related emissions arises from biogenic sources from agriculture and waste disposal, including enteric fermentation, animal and human wastes, rice paddies, biomass burning, and landfills. Emissions also result from fossil fuel-related methane sources such as natural gas loss, coal mining, and the petroleum industry. Methane is emitted naturally by wetlands, termites, other wild ruminants, oceans, and hydrates. Based on recent estimates, current human-related biogenic and fossil fuel-related sources for methane are ~275 and 100 $TgCH_4$/year, whereas total natural sources are ~160 $TgCH_4$/year.

Emissions of sulfur dioxide and other gases can result in the formation of aerosols that can affect climate. Aerosols affect climate directly by absorption and scattering of solar radiation and indirectly by acting as cloud condensation nuclei. A variety of analyses indicate that human-related emissions of sulfur, and the resulting increased sulfuric acid concentrations in the troposphere, may be cooling the Northern Hemisphere sufficiently to compensate for a sizable fraction of the warming expected from greenhouse gases. Because the lifetime in the lower atmosphere of these aerosols is typically only ~1 wk, the large continual emissions of the aerosol precursors largely determines the impact of the aerosols on climate. Large volcanic explosions can influence climate for periods of 1 to 3 years through emissions of sulfur dioxide, and the resulting sulfate aerosols, into the lower stratosphere. More than one-half of the sulfur dioxide, $SO_2$, emitted into the atmosphere comes from human-related sources, mainly from the combustion of coal and other fossil fuels. Most of these emissions occur in the Northern Hemisphere. Analyses indicate that anthropogenic emissions have grown dramatically during this century. Other aerosols are also important to climate. Of particular interest are the carbonaceous aerosols or black carbon (soot) aerosols that are absorbers of solar and infrared radiation and can thus add to the concerns about warming.

## Projected Changes in Climate

A perturbation to the atmospheric concentration of an important greenhouse gas, or the distribution of aerosols, induces a radiative forcing that can affect climate. Radiative forcing of the surface-troposphere system is defined as the change in net radiative flux at the tropopause due to a change in either solar or infrared radiation. Generally, this net flux is calculated after allowing for stratospheric temperatures to readjust to radiative equilibrium. A positive radiative forcing tends on average to warm the surface; a negative radiative forcing tends to cool the surface. This definition is based on earlier climate modeling studies, which indicated an approximately linear relationship between the global mean radiative forcing at the tropopause and the resulting global mean surface temperature change. However, recent studies of greenhouse gases indicate that the climatic response can be sensitive to the altitude, latitude, and nature of the forcing.

The resulting change in radiative forcing can then drive changes in the climate. A positive radiative forcing tends on average to warm the Earth's surface; a negative radiative forcing tends to cool the surface. Changes in radiative forcing can occur either as a result of natural phenomena or due to human activities. Natural causes for significant changes in radiative forcing include those due to changes in solar luminosity or due to concentrations of sulfate aerosols after a major volcanic eruption. Human-related causes include the changes in atmospheric concentrations of greenhouse gases and in aerosol loading discussed above.

Analyses of the direct radiative forcing due to the changes in greenhouse gas concentrations since the beginning of the Industrial Era give an increase of ~2.3 $Wm^{-2}$. To put this into perspective, a doubling of $CO_2$ from preindustrial levels would correspond to ~4 $Wm^{-2}$; climate models studies indicate this would give a 1.5 to 4.5°C increase in global temperature. Approximately 0.5 $Wm^{-2}$ of the increase has occurred within the last decade. By far the largest effect on radiative forcing has been the increasing concentration of carbon dioxide, accounting for ~64% of the total change in forcing. Methane has produced the second largest change in radiative forcing of the greenhouse gases. Whereas water vapor is the most important natural greenhouse gas, its global atmospheric concentrations are not thought to be significantly affected by human activities; therefore, only the feedback of its concentration (a warmer atmosphere holds more water vapor) resulting from the externally forced factors on climate is considered in climate projections.

Changes in the amounts of sulfate, nitrate, and carbonaceous aerosols induced by natural and human activities have

all contributed to changes in radiative forcing over the past century. The direct effect on climate from sulfate aerosols occurs primarily through the scattering of solar radiation. This scattering produces a negative radiative forcing and has resulted in a cooling tendency on the Earth's surface that counteracts some of the warming effect from the greenhouse gases. In the global average, increases in amounts of carbonaceous aerosols, which absorb solar and infrared radiation, have likely counteracted some of the effect of the sulfate aerosols. Aerosols also can produce an indirect radiative forcing by acting as condensation nuclei for cloud formation. There is still a large uncertainty in determining the extent of radiative forcing that has resulted from this indirect effect.

Changes in tropospheric and stratospheric ozone also affect climate, but the increase in tropospheric ozone over the past century and the decrease in stratospheric ozone over recent decades have had a relatively small combined effect on radiative forcing compared with $CO_2$. The radiative forcing from the changes in amount of stratospheric ozone, which has primarily occurred over the past few decades primarily as a result of human-related emissions of halogenated compounds containing chlorine and bromine, is generally well understood. However, the changes in concentrations of tropospheric ozone over the past century, and the resulting radiative forcing, are much less well understood.

Changes in the solar energy output reaching the Earth is also an important external force on the climate system. The sun's output of energy is known to vary by small amounts over the 11-year cycle associated with sunspots, and there are indications that the solar output may vary by larger amounts over longer periods. Slow variations in the Earth's orbit, over time scales of multiple decades to thousands of years, have varied the solar radiation reaching the Earth, and have affected the past climate. Solar variations over the past century are thought to have had a small but important effect on the climate. Through satellite observations, we know the sun is not important in explaining the large increase in temperatures over the past few decades.

Evaluation of the radiative forcing from all of the different sources since preindustrial times indicates that globally averaged radiative forcing on climate has increased. Because of the hemispheric and other inhomogeneous variations in concentrations of aerosols, the overall change in radiative forcing is much greater or much smaller at specific locations over the globe.

To study the potential implications on climate from further changes in human-related emissions and atmospheric composition, a range of scenarios for future emissions of greenhouse gases and aerosol precursors has been produced by the IPCC Special Report on Emission Scenarios (SRES) for use in modeling studies to assess potential changes in climate over the next century for the current IPCC assessment of climate change. None of these scenarios should be considered as a prediction of the future, but they do illustrate the effects of various assumptions about economics, demography, and policy on future emissions. Each scenario is based on a narrative storyline, describing alternative future developments in economics, technical, environmental, and social dimensions. Details of these storylines and the SRES process can be found elsewhere. These scenarios are generally thought to represent the possible range for a business-as-usual situation where there has been no significant efforts to reduce emissions to slow down or prevent climate changes. The resulting derived radiative forcing increases by 7 $Wm^{-2}$ by 2100 for high scenarios and 4.7 $Wm^{-2}$ for low scenarios relative to beginning of the Industrial Era. As a result, each of the scenarios implies a significant warming tendency. Direct effects of aerosols are included in this analysis but indirect effects and effects on ozone are not considered.

The response of the climate system to the changes in radiative forcing is determined by the climate sensitivity defined as the equilibrium surface temperature increase for doubling of atmospheric $CO_2$ concentration. This parameter is intended to account for all the climate feedback processes not modeled explicitly. Model-calculated changes in global mean surface temperature for the various SRES scenarios, assuming a central value for the climate sensitivity of 2.5°C, show that surface temperature is projected to increase by ~1.8 to 2.6°C by 2100 relative to 1990 for this assumed climate sensitivity. The full range of uncertainty in the climate sensitivity would be presented by a broader range of 1.5 to 4.5°C for a doubling of $CO_2$ concentration (this reflects the analyzed uncertainty in current models of the complex climate system). Accounting for this uncertainty, the scenarios would give an increase in global surface temperature of ~1.3 to 5°C for the four scenarios.

## Climate Change in the U.S. Midwest

Climatic trends in the Midwest are characterized by high variability on time scales of one to several years relative to long-term trends. It is not uncommon for temperature on a winter's day to vary by as much as 17°C from the long-term or century-scale mean, and for a summer's day temperature to vary by 8°C. For a given year, the seasonal temperature anomaly can vary by 4°C from the long-term mean. This high variability often makes it difficult to detect whether long-term trends are occurring. However, since the 1970s temperatures have ranged from near average to somewhat above average in comparison with earlier in the twentieth century, particularly in the winter, where two-thirds of the winters over the past 15 years have been above the long-

term average. In the most recent 4 years, annual average temperatures have all been 1–2°C above the long-term average, similar to other warm periods such as the early 1930s and early 1950s.

Interannual variations in precipitation range from –40 to 100% from the mean for a given year. On a seasonal basis, the variation is larger in winter, where precipitation can range from –50 to +90% from the mean, whereas summer variations are smaller, at ±40%. Observed precipitation has generally been above average relative to the previous century since around 1970. In the Midwest, changes in climate have already been demonstrated over the past century through warmer winters, shorter ice-free seasons, longer growing seasons, and increases in heavy rainfall events.

Wuebbles and Hayhoe (2004) combine the latest global climate model (GCM) projections with historical records of observed climate over the past century to provide an updated picture of the potential impacts of climate change on the Midwest. They recognize that significant uncertainties are inherent to application of GCM data at a regional scale; however, when combined with a detailed historical record, this analysis does provide valuable information regarding the possible range of future change in this region. In addition, actual impacts of climate change are often critically dependent on localized features of climate that may not be represented adequately when averaged on the coarse resolution of a typical GCM grid (e.g., recent studies suggest that global climate models may overestimate climate changes in the Midwest as a result of scale issues affecting the ability to adequately represent the interactions between soil moisture, surface winds, and temperature).

Projected changes in climate based on GCM projections have been determined relative to a baseline, here taken as climate averaged over the period 1961–1990. These results suggest that annual average daily maximum temperatures for the "mid-range" SRES scenarios could increase 3–6°C over the Great Lakes area by the end of the next century, with changes varying by season. When the high and low SRES scenarios are included, this range increases to 3–7°C in winter and 4–11°C in summer. Warming is expected to vary across the region. In winter, one model shows a strong N/S gradient (for the A2 mid-range scenario averaged over 2070–2099, with the greatest warming at higher latitudes, whereas the other model shows a greater warming in the westward part of the region. In summer, both models show greatest change over the southern and western part of the region.

According to the latest model results, average winter precipitation across the region is likely to increase, whereas summer precipitation remains the same or decreases (Figure 1b). Both models project increases in winter average precipitation up to 30% by the end of the century, with largest increases occurring over northern and western states. The geographical distribution of summer changes in temperature is ambiguous, with one model projecting slight decreases in the north and similar increases in the south, whereas the other projects decreases up to 30% across the region.

## Potential Impacts of Climate Change

At this point, potential changes in climate globally are better understood than the changes that could occur locally or regionally. However, the impacts of interest from climate change are primarily local to regional in scale. As discussed in NAST (2001), Kling et al. (2003), and Wuebbles and Hayhoe (2004), climate change has the potential to significantly affect agriculture, ecosystems, water resources, and human health and welfare throughout the Midwest and Great Lakes regions. The impacts could be large enough that they should be included in considering future policy decisions affecting existing human and natural systems in the region. All of these areas are already under stress from pressures exerted by our expanding population, growing economy, and continuing urbanization. Policies to address current concerns also must consider the potential impacts of climate change on each of these areas if they are to succeed in adapting to or mitigating the effects we are having on our environment.

## References

(IPCC) Intergovernmental Panel on Climate Change. 2001. Climate change 2001: the scientific basis, in Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., ven der Linden, P.J., Dai, X., Maskell, K., and Johnson, C.A. eds). Cambridge University Press, Cambridge, United Kingdom.

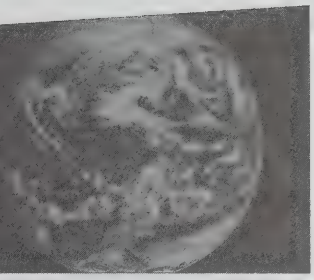
Kling, G., K. Hayhoe, L. Johnson, J. Magnuson, S. Polasky, S. Robinson, B. Shuter, M. Wander, D. Wuebbles, D. Zak, R. Lindroth, S. Moser, and M. Wilson. 2003. Confronting climate change in Great Lakes region. A report of the Ecological Society of America and the Union of Concerned Scientists, Washington, DC.

(NAST) National Assessment Synthesis Team. 2001. Climate change impacts on the United States: the potential consequences of climate variability and change. Report for the U.S. Global Change Research Program. Cambridge University Press, Cambridge, United Kingdom.

Wuebbles, D.J., and A.K. Jain. 2001. Concerns about climate change and the role of fossil fuel use. Fuel Processing Technology 71: 99–119.

Wuebbles, D.J., and K. Hayhoe. 2004. Climate change in the Midwest: informing regional policy decisions. Mitigation and Adaptation Strategies for Global Change 9: 335–363.

# Climatological Changes: Implications for Agriculture



*Michelle M. Wander and Steve Hollinger*

Climatological change has and will continue to shape agriculture in our region. Model-based predictions for agriculture have been relatively mild; however, newer projections are increasingly negative as the consequences of increased precipitation and flooding, ozone damage, and their interactions with pests and risk are considered. Climate-based predictions made at regional scales can be difficult to relate to trends observed in producers' fields where changes in precipitation and humidity are already apparent. Inclement weather has been tied to increased year-to-year yield variability and thus higher risk. During the next 50 years, changes in the hydrologic cycle will have a greater influence on production and environmental outcomes than will atmospheric composition or rising temperatures. Crop growth models, which are typically tied to larger climate-based models, fail to adequately describe the factors that determine yield. Very short periods of unfortunately timed stress (e.g., moisture surpluses, deficits, cloud cover, and pest pressure) are reducing grain yield in Illinois. Soil erosion and runoff of agricultural wastes will increase with flooding and intense rainfall events, and the consequences for agriculture and associated resources will depend upon the choices made within the context of changing markets, technologies, and social priorities. By implementing production strategies that conserve soil and water and reduce energy consumption or even produce energy, agriculture can help minimize climatological change.

## Trends

Agriculture in the Great Lakes basin must prepare for a climate that may be similar to that presently experienced in the southeastern United States, which is marked by summer drought and spring and winter flooding. Already, we see evidence of climatic change in the Great Lakes region. Average annual air and soil temperatures are increasing, whereas winters are getting shorter (Karl et al. 1996, Hu and Feng 2004). By the end of the 21st century maximum daily temperatures could rise by 5–14°F in both winter and summer. This warming is more intense than any seen since the last ice age. By the end of the century, the growing season could be 4–9 weeks longer, but the number of extremely hot days (exceeding 90°F) could increase. In the central United States between 1982 and 1999, both measured precipitation (Mauget 2003) and the frequency of heavy rainfall events and flooding (Kunkel et al. 1999, Kunkel 2003) have increased significantly. The frequency of heavy 24-hour rainstorms, which have already nearly doubled over the past century, will continue to increase and by 2100 could be another 50–100% higher than they are today. Given the nature of these storm events (predominantly convective storm events), the region may see an increase in the number of associated severe thunderstorms and wind storms, including tornadoes (Raddatz 2003). Despite increases in amount and intensity of precipitation, the frequency of summer rain has not increased during the last century (Karl and Knight 1998). In the near term, however, moisture deficits are being mitigated by climate-induced reductions in transpiration associated with increased cloud cover and humidity (Golubev et al. 2001, DeGaetano and Eggleston 2003). By reducing radiation, this increase in cloud cover can reduce the yields of corn and other C4 crops. By the end of the century, the combination of increased summer temperature, evaporation, and runoff from intense rainfall events, accompanied by a decline in summer precipitation, will increase drought frequency. By the end of the century, soil moisture is projected to increase by as much as 80% in the winter at some locales, but it will decline by 30% regionally on average (Wuebbles and Hayhoe 2004).

## Impacts on Agriculture

Large-scale climatic change predictions typically indicate production patterns are likely to shift regionally, with prime production conditions moving north (Doering et al. 2002) where soils are relatively thin and infertile (FAO 1975). Early predictions suggest these trends will not seriously disrupt the nation's agricultural capacity over the next 100 years (Adams et al. 1999a, IPCC 2001b, Reilly and

Graham 2001, Reilly et al. 2001); however, newer models that consider climate interactions with other influential factors suggest prospects might not be so rosy. For example, the "$CO_2$ fertilization effect" and expanded growing season length are not expected to increase yield to the extent previously thought (Changnon and Hollinger 2003). We now recognize that higher ozone concentrations can counter the positive impacts $CO_2$ fertilization, particularly for sensitive crops, including soybean and horticultural crops (Benton et al., 2000, Morgan et al. 2003). The assumption that $CO_2$ stimulation of crop growth will be the main factor driving agriculture's climate response (Hasskett et al. 1997) has been supplanted by the realization that changes in weather, and not necessarily the composition of the atmosphere, will be a main determinate of production in the Great Lakes region (Fuhrer 2003). Newer crop growth models increasingly include the negative consequences of increased precipitation and flooding (Rosenzweig et al. 2002) and consider how moisture stress influences crop growth and development (Haskett et al. 2000; Wolf 2002a,b).

## Row Crop Production

Crop production in the region is already suffering from problems associated with both excess and insufficient moisture, including waterlogging, delayed planting, and increased disease incidence, which is accelerated by high heat (Yang and Scherma 1997, Rosenzweig et al. 2001). Soil moisture stress already limits soybean yield, explaining more than 48% of yield variability in 30 sites studied in Iowa (Irmak et al. 2002). Four days of ill-timed soil moisture stress can reduce corn yield by 50%. Increases in precipitation and available moisture could be an advantage to rain-fed crops during the first half of the century, potentially reducing the number of irrigated acres of grain in the short-term before climate ultimately dries. By the century's end, when drier conditions and increased drought prevail, investment in irrigation may become necessary. The effects of climate change on pest outbreaks will be complex and are likely to be site- and interaction-specific, with outcomes dependent on the initial state and the dominant species within each plant, insect herbivore, and pathogen community (Lindroth et al. 2001, Fuher 2003, Hartley and Jones 2003, Stacey 2003).

## Adaptation

Those involved in agriculture have always been acutely aware of the importance of weather. Coping with increased frequency of both extreme precipitation events and overall drying will be an increasing challenge as farmers and agricultural industries face increasing global competition. Historic trends in yield increases, crop breeding technologies, the rapid spread of cropping systems far beyond their traditional boundaries, and the flexibility in international trade systems indicate agriculture will cope effectively with climatic change (Reilly et al. 2003). Apart from extreme events, farmers can adapt to moderate changes in temperature or precipitation if such changes can be predicted. Knowing that conditions will be warmer and drier, or warmer and wetter, will allow farmers to plant varieties better suited to such conditions. Crop growth models will be helpful guides to tactical adaptations, indicating, for example, when planting date is more important than cultivars (Wolf 2002b), how cultivar selection interacts with climate to affect grain drying demands (Magari et al. 1997), or when pest outbreaks are more or less likely (Landsberg and Stafford-Smith 1992). Agriculture can contribute to reduced emissions by improving energy efficiency of production and processing, by helping to mitigate or minimize green house gas emissions, and by reducing dependence of foreign oil by contributing to clean energy production (Metting et al. 2001, Wander and Nissen 2004). Negative impacts on the environment must be minimized as capacity to cope with or buffer climate stress is enhanced. Proactive measures can help conserve the productive potential of the region's soils, stream, and wetland resources and reduce off-farm costs of erosion and nutrient export.

*Note: Much of this text is adapted from material developed by Michelle Wander for an article submitted to Renewable Agriculture and Food Systems.*

## References


Adams, R.M., B.H. Hurd, and J. Reilly. 1999. Agriculture and global climate change. A review of impacts to U.S. Agricultural Resources. Pew Center on Global Climate Change, Arlington, VA.

Benton, J., J. Fuhrer, B.S. Gimeno, L. Skarby, D. Palmer-Brown, G. Ball, C. Roadknight, and G. Mills. 2000. An international cooperative programme indicates the widespread occurrence of ozone injury on crops. Agriculture Ecosystems and Environment 78: 19–30.

Changnon, S.A. and S.E. Hollinger. 2003. Problems in estimating impacts of future climate change on Midwestern corn yields. Climatic Change 58: 109–118.

DeGaetano, A.T. and K.L., Eggleston. 2003. Temporal variations in model-derived evapotransporation in the northeastern and Midwestern U.S. American Meteorological Society, Seattle, WA.

Doering III, O.C., C. Randolph, J. Southworth, and R.A. Pfeifer [eds.]. 2002. Effects of climate change and variability on agricultural production systems. Kluwer Academic Publishers, Boston, MA.

Fuhrer, J. 2003. Agroecosystern responses to combinations of elevated CO2, ozone, and global climate change. Agriculture Ecosystems and Environment 97: 1–20.

Golubev, V.S., J.H. Lawrimore, P. Ya. Groisman, N.A. Speranskaya, S.A. Zhuravin, M.J. Menne, T.C. Peterson, and R.W. Malone. 2001. Evaporation changes over the contiguous United States and the former USSR: a reassessment. Geophysical Research Letters 28: 2665–2668.

Hartley, S.E. and T.H. Jones. 2003. Plant diversity and insect herbivores: effects of environmental change in contrasting model systems. Oikos 101: 6–17.

Haskett, J.D.; Y.A. Pachepsky, and B. Acock. 1997. Increases in atmospheric $CO_2$ and climate change effects on Iowa soybean yield, simulated using GLYCIM. Agronomy Journal 89: 167–176.

Haskett, J.D., Y.A. Pachepsky, and B. Acock. 2000. Effect of climate and atmospheric change on soybean water stress: a study of Iowa. Ecological Modeling 135: 265–277.

Hu, Q. and S.A. Feng. 2003. A daily soil temperature dataset and soil temperature climatology of the contiguous United States. Journal of Applied Meteorology 42: 1139–1156.

Irmak, A., W.D. Batchelor, J.W. Jones, S. Irmak, J.O. Paz, H.W. Beck, and M. Egeh. 2002. Relationship between plant available soil water and yield for explaining soybean yield variability. Applied Engineering in Agriculture 18: 471–482.

Karl, T.R., R.W. Knight, D.R. Easterling, and R.G. Quale. 1996. Indices of climate change for the United States. Bulletin of the American Meteorological Society 77: 279–292

Karl, T.R. and R.W. Knight. 1998. Secular trends of precipitation amount frequency and intensity in the United States. Bulletin of the American Meteorological Society 79: 231–241.

Kunkel, K.E., K. Andsager, and D.R. Easterling. 1999. Long term trends in heavy precipitation events over North America. Journal Climate 12: 2513–2525.

Kunkel, K.E. 2003. North American trends in extreme precipitation. Natural Hazards 29: 291–305.

Landsberg, J. and M. Stafford-Smith. 1992. A functional scheme for predicting the outbreak potential of herbivorous insects under global atmospheric change. Australian Journal of Botany 40: 565–577.

Lindroth, R.L. 1996. Consequences of elevated atmospheric $CO_2$ for forest insects, in Carbon Dioxide, Populations, and Communities (C. Körner and F.A. Bazzaz [eds]) pp 347-361. Academic Press, San Diego.

Margari, R., M.S. Kang, and Y. Zhang. 1997. Genotype by environment interaction for ear mositure loss rate in corn. Crop Science 37: 774–779.

Mauget, S.A. 2003. Intra- to multidecadal climate variability over the continental United States: 1932-99. Journal of Climate 16: 2215–2231.

Metting, F.B., J.L. Smith, J.S. Amthor, and R.C. Izaurralde. 2001. Science needs and new technology for increasing soil carbon sequestration. Climatic Change 51: 11–34.

Morgan P.B., E.A. Ainsworth, and S.P. Long. 2003. How does elevated ozone impact soybean? A meta-analysis of photosynthesis, growth and yield. Plant Cell and Environment 26: 1317–1328.

Raddatz, R.L. 2003. Agriculture and tornadoes on the Canadian prairies: potential impacts of increasing atmospheric $CO_2$ on summer severe weather. *Natural Hazards* 290: 113–122.

Reilly, J. and J. Graham. 2001. Changing climate and changing agriculture: report of the agricultural sector assessment team. U.S. National Assessment. National Program Office, Washington, DC.

Reilly et al., 2001. Agriculture: the potential for consequences of climate variability and change for the United States, in US National Assessment of the Potential Consequences of Climate Variability and Change, pp 379–403. US Global Change Research Program. Cambridge University Press, Cambridge, MA.

Reilly et al., 2003. U.S. Agriculture and climatic change: new results. Climatic Change 57: 43–69.

Rosenzweig, C., A. Iglesias, X.B. Yang, P.R. Epstein, and E. Chivian. 2001. Climate changes and U.S. agriculture: the impacts of warming and extreme weather events on productivity, plant diseases, and pests. Global Change and Human Health 2: 90–105.

Wolf, J. 2002a. Comparison of two potato simulation models under climate change. I. Model calibration and sensitivity analyses. Climate Research 21: 173–186.

Wolf, J. 2002b. Comparison of two soybean simulation models under climate change. I. Model calibration and sensitivity analyses. Climate Research 20: 55–70.

Wander M. and T. Nissen. 2004. Value of soil organic carbon in agricultural lands. Mitigation and Adaptation Strategies for Global Climate Change 9: 417-431.

Wuebbles, D. and K. Hayhoe. 2004. Climate change projections for the United States Midwest. Mitigation and Adaptation Strategies for Global Climate Change 9: 335–363.

Yang, X.B. and H. Scherm. 1997. El Nino and infections disease. Science 275: 739.

# Elevated Ozone and Carbon Dioxide: Implications for Agriculture

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Predicted global climate change is driven by increasing concentrations of greenhouse gases in the atmosphere. In addition to causing climate change, two of these gases have direct effects on crop plants: carbon dioxide and ozone. The concentration of carbon dioxide in the atmosphere ($[CO_2]$) has increased from ~260 ppm, in the early 1800s to 374 ppm today, and it is expected to reach 550 ppm by the middle of this century (IPCC 2001). Ozone in the stratosphere, the layer of the atmosphere between ~10 and 50 km above the Earth's surface, absorbs UV radiation and protects the surface. Its concentration has been falling. By contrast, ozone concentration in the troposphere ($[O_3]$), the lowest layer of the atmosphere and that in contact with the surface, has been rising. Unlike $CO_2$, $O_3$ is relatively short-lived in the troposphere, formed by the action of sunlight on nitrogen oxides in polluted air masses. Although $[CO_2]$ is remarkably constant across the globe, $[O_3]$ varies with location, weather, time of day, and time of year. The Midwest has some of the highest background levels in the world, whereas levels in other major corn- and soybean-growing areas are low; notably, South America. However, levels in China are rising rapidly and predicted to exceed those of the Midwest during this century (IPCC 2001). Although emission controls have decreased peak $[O_3]$ around cities, background levels in rural areas continue to rise. This rise is the result of long-distance transport, including intercontinental transfer as well as conditions more favorable to formation of $O_3$ in rural areas. Peak growing season concentrations in the early 1800s were probably ~5–10 ppb, compared with 50–60 ppb in central Illinois today; $[O_3]$ in Illinois is estimated to rise a further 20% by 2050 (IPCC 2001).

## Meta-analysis of Factors Potentially Affecting Insect Pests

There have been many previous studies of the effects of elevated $[CO_2]$ and elevated $[O_3]$ on soybean. These studies have used a wide range of germplasms, soils, locations, climates, and experimental designs. Fumigation treatments have been conducted in greenhouses, laboratory-controlled environments, transparent field chambers, and open-topped chambers, i.e., chambers with transparent walls, but open to the atmosphere at the their top. This diversity of experiments has yielded a range of findings, some contradictory. Meta-analysis provides a statistical technique for quantitatively reviewing such varied studies and finding the average response and its confidence limits. Figure 1 summarizes 111 peer-reviewed journal publications (1983–2001) that studied the effects of an approximate doubling of $[CO_2]$ on soybean growth. Photosynthesis at the leaf and whole plant level was strongly increased, resulting in increased assimilate supply throughout the life of the plant. Stomatal conductance, however, was significantly decreased (Figure 1) with the result that less water will be transpired, making leaf surfaces and crop canopies drier microenvironments for insect pests and their predators. Although total leaf area is increased, leaves are denser per unit leaf area and are a smaller proportion of the total plant mass. The most notable change in leaf chemistry is that starch content (the largest portion of the nonstructural carbohydrates) is more than doubled. Sucrose content is increased by 25%. There are small but significant decreases in leaf nitrogen (N) and in Rubisco (the most abundant leaf soluble protein) of 6 and 11%, respectively. The increase in starch may favor chewing-insect guilds, although all insect pests would need to consume more leaf material to obtain the amount of nitrogen that they currently ingest.

Elevated $[O_3]$, in many respects, has opposite effects to elevated $[CO_2]$. Based on 53 prior studies, it decreases leaf photosynthesis, total leaf area, and nonstructural carbohydrate content. In common with elevated $[CO_2]$, it significantly decreases stomatal conductance. Therefore, in ]common with elevated $[CO_2]$, rising $[O_3]$ is likely to make the leaf surface, and soybean crop canopy in general, a less humid and warmer environment (warmer because latent heat of cooling due to transpiration will be less).

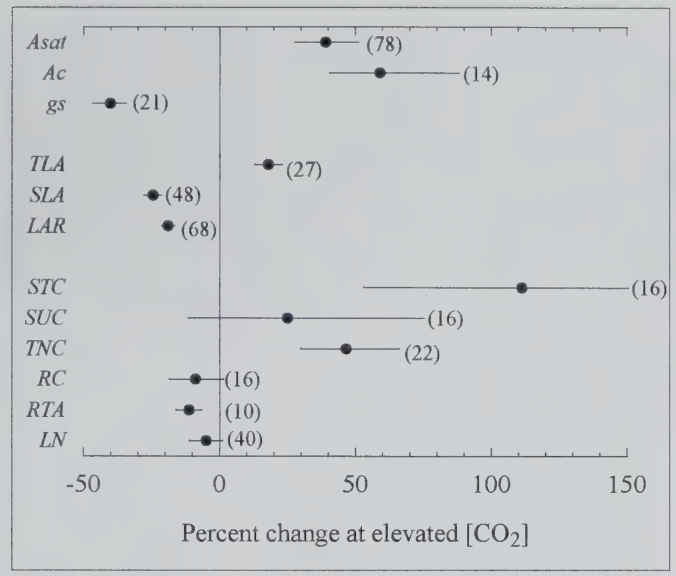


**Figure 1.** Effect of growth at [$CO_2$] elevated to ~700 ppm on soybean light saturated photosynthesis ($A_{sat}$), crop photosynthesis ($A_c$), stomatal conductance ($g_s$), total leaf area (TLA), specific leaf area (area per unit leaf mass, SLA), leaf area ratio (area per unit plant mass, LAR), and a series of biochemical parameters expressed on a mass per unit leaf area basis: starch (STC), sucrose (SUC), total nonstructural carbohydrates (TNC), Ribulose-1:5-bishosphate carboxylase/oxygenase (Rubisco, RC), and total nitrogen (LN). The activity of Rubisco per unit leaf area (RTA) also is shown. Solid circles indicate the percentage of change in elevated [$CO_2$] relative to control plants grown at the current concentration. Bars around the points indicate the 95% confidence limits, and the numbers in parentheses, the number of independent studies from which the mean responses are derived. (Redrawn from Ainsworth et al. 2002).

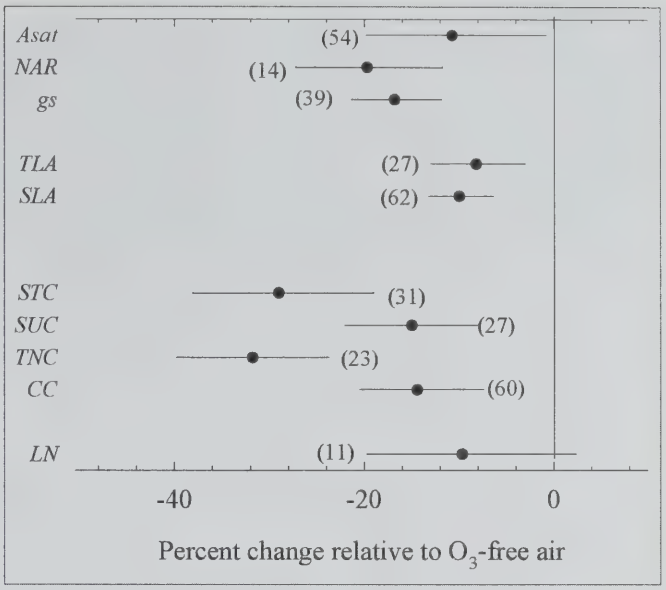


**Figure 2.** Effect of growth in [$O_3$] elevated to a mean of ~60 ppb relative to soybean plants grown in carbon-filtered air. Symbols, bars, and abbreviations as in Figure 1. CC represents chlorophyll content of leaves. Redrawn from Morgan et al. (2003).

Both factors are likely to affect the activity of insect pests and their predators. Lower stomatal conductance also may affect emission of any attractants or repellants released by leaves. Although not statistically significant, a decrease in leaf nitrogen also is indicated. Chlorophyll contains nitrogen, and its decrease also indicates a decrease in the proteins necessary to bind the pigment (Morgan et al. 2003). Other studies have indicated a decrease in Rubisco content (Long and Naidu 2002). Therefore, in common with elevated [$CO_2$], rising [$O_3$] is likely to decrease the availability of nitrogen to insect pests feeding on leaves. However, leaves have a shorter life span in elevated [$O_3$], with the result that nitrogen is remobilized at greater rates, such that although N content per unit leaf area is lower, N content of the phloem sap may be higher. Thus, the nitrogen implications may be different for phloem-feeding versus leaf-chewing pests.

## Free-Air Concentration Enrichment and SoyFACE

The prior studies of the effects of future elevated [$CO_2$] and [$O_3$] on soybean have been conducted in partially or wholly enclosed environments. These environments themselves have major affects on plant growth and development, and thus there is uncertainty about the extent to which elevated [$CO_2$] and [$O_3$] may apply in the open field. Free-air concentration enrichment (FACE) technology now provides a means to simulate the future atmosphere within field crops, without otherwise altering the microenvironment (McLeod and Long 1999). Enclosures will exclude or at the least strongly affect movement of pests; FACE has a very clear advantage here. SoyFACE is a facility established at the University of Illinois, in which soybean is grown from sowing to harvest in the [$CO_2$] or/and [$O_3$] anticipated for the middle of this century (Ainsworth et al. 2003; Morgan et al. 2004; www.soyface.uiuc.edu), that is, an elevation of [$CO_2$] to 550 ppm and of [$O_3$] by 25% above current. The facility includes 32 circular plots of 20 m in diameter within a 32-ha field. One-half of the plots and field in any one year are in soybean, and the other one-half in corn. Within the soybean crop, four plots are at current [$CO_2$] and [$O_3$] levels, four in elevated [$CO_2$], four in elevated [$O_3$], and four combine elevation of [$CO_2$] and [$O_3$]. This is the first experiment to investigate the impacts of both gases on an annual crop under fully open-air conditions. Results so far suggest that the impacts of elevated [$CO_2$] on pho-

tosynthesis and production, although significant, are less than anticipated from enclosure studies (Rogers et al. 2004, Morgan et al., 2005a). The effect of $[O_3]$ on photosynthesis also is less than expected, whereas loss of production is as large as predicted (Morgan et al., 2004, 2005b). Elevated $[CO_2]$ increased yield by 20%, whereas elevated $[O_3]$ lowered yield by 20%. One of the most notable differences between FACE and enclosure studies is in leaf carbohydrates under elevated $[CO_2]$. Whereas starch was strongly increased in enclosure studies (>100%), in SoyFACE the increase was only ~20%. Changes in sugars were similarly smaller, except in late seed fill, when sucrose and glucose were more than doubled in elevated $[CO_2]$ versus control. As predicted from the enclosure studies, both treatments significantly decreased stomatal conductance and transpiration (Morgan et al. 2004, Rogers et al. 2004). Also as predicted, Rubisco activity is decreased by both treatments (Bernacchi et al. 2004, Rogers et al. 2004), suggesting that nitrogen availability to pests may be decreased.

In conclusion, the greenhouse gases $CO_2$ and ozone will not only produce changes in climate that will affect crops and their pests but also will have major direct effects on the quality of crop tissues that will affect pest performance. The most obvious effects will be increased availability of carbohydrates and decreased availability of nitrogen, whereas decreased stomatal opening will create a drier and warmer leaf and crop canopy microenvironment. How the two gases will interact is uncertain, and the current focus of research is within SoyFACE.

## References


Ainsworth, E., P. Davey, C. Bernacchi, O. Dermody, E. Heaton, D. Moore, P. Morgan, S. Naidu, H. Yoo Ra, X. Zhu, P. Curtis, and S. Long (2002) A meta-snalysis of elevated $[CO_2]$ effects on soybean (*Glycine max*) physiology, growth and yield. Global Change Biology 8: 695–709.

Ainsworth, E.A., A. Rogers, R. Nelson, and S.P. Long (2004) Testing the "source-sink" hypothesis of down-regulation of photosynthesis in elevated $CO_2$ in the field with single gene substitutions in *Glycine max*. Agricultural and Forest Meteorology 122: 85–94.

Bernacchi C.J., P.B. Morgan, D.R. Ort, and S.P. Long (2004) The growth of soybean under free air $[CO_2]$ enrichment (FACE) stimulates photosynthesis while decreasing in vivo Rubisco capacity. Planta 219 (in press).

[IPCC] Intergovernmental Panel on Climate Change (2001) Climate change 2001: the scientific basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge.

Long, S.P., E.A. Ainsworth, A. Rogers, and D.R. Ort (2004) Rising atmospheric carbon dioxide: plants face the future. Annual Review of Plant Biology 55: 591–628.

Long, S., and S. Naidu (2002) Effects of oxidants at the biochemical, cell and physiological levels, with particular reference to ozone, in Air Pollution and Plant Life (B. JNB and T. M. eds), pp 69–88. John Wiley, Chichester.

McLeod, A., and S. Long (1999) Free-air carbon dioxide enrichment (FACE) in global change research: a review. Advances in Ecological Research 28: 155.

Morgan, P.B., E.A. Ainsworth E.A., and S.P. Long (2003) How does elevated ozone impact soybean? A meta-analysis of photosynthesis, growth and yield. Plant Cell and Environment 26: 1317–1328.

Morgan, P.B., C.J. Bernacchi, D.R. Ort, and S.P. Long (2004) An in vivo analysis of the effect of season-long open-air elevation of ozone to anticipated 2050 levels on photosynthesis in soybean. Plant Physiology 135: 2348–2357.

Morgan, P.B., G. Bollero, R.L. Nelson, F.G. Dohleman, and S.P. Long (2005) Smaller than predicted increase in above-ground net primary production and yield of field-grown soybean was found when $[CO_2]$ is elevated in fully open-air. Global Change Biology 11 (in press).

Morgan, P.B., G. Bollero, R.L. Nelson, and S.P. Long (2005) Season-long elevation of ozone concentration by 20% under fully open-air conditions decreases the growth and production of Midwest soybean crops by ca. 20%. Environmental Pollution (in press).

Rogers, A., D.J. Allen, P.A. Davey, P.B. Morgan, E.A. Ainsworth, C.J. Bernacchi, G. Cornic, O. Dermody, F.G. Dohleman, E.A. Heaton, J. Mahoney, X.G. Zhu, E.H. Delucia, D.R. Ort, and S.P. Long (2004) Leaf photosynthesis and carbohydrate dynamics of soybeans grown throughout their life-cycle under free-air carbon dioxide enrichment. Plant Cell and Environment 27: 449–458.

# Influence of Elevated Ozone and Carbon Dioxide on Insect Densities

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The combustion of fossil fuels is profoundly altering the chemical composition of the atmosphere. Beginning with the Industrial Revolution, the concentration of carbon dioxide in the atmosphere has increased from approximately 280 to 370 $l^{-1}$ in 2004, and it is expected to exceed 550 $l^{-1}$ by 2050. Tropospheric ozone has risen even more rapidly than $CO_2$ and average summer concentrations in the Northern Hemisphere are expected to continue to increase by 0.5–2.5% per year over the next 30 years. Although elevated $CO_2$ stimulates photosynthesis and productivity of terrestrial ecosystems, ozone ($O_3$) is deleterious. In addition to directly affecting the physiology and productivity of crops, increased concentrations of tropospheric $CO_2$ and $O_3$ are predicted to lower the nutritional quality of leaves, which has the potential to increase herbivory as insects eat more to meet their nutritional demands.

We tested the hypothesis that changes in tropospheric chemistry affect the relationship between plants and insect herbivores by changing leaf quality. The susceptibility to herbivory of soybean grown in elevated $CO_2$ or $O_3$ was examined using free air gas concentration enrichment (SoyFACE).[1] FACE technology has the advantage that plants are cultivated under realistic field conditions with no unwanted alteration of microclimate or artificial constraints on the insect community.

Elevated $CO_2$ (~550 $l^{-1}$) substantially increased susceptibility of soybean to herbivory early in the season, whereas $O_3$ seemed to have no effect. For plants grown at 550 $l^{-1}$ $CO_2$, the percentage of leaf tissue removed by herbivores was more than twice the level for plants in ambient air (Fig. 1); there was no effect of elevated $O_3$ on herbivory during this first year, but the $O_3$ concentration was elevated to only 1.2× ambient. The increase in herbivory under elevated $CO_2$ was consistent with the corresponding increase in the size of insect populations, and the majority of leaf tissue was removed by the invasive Japanese beetle, *Popillia japonica*. Subsequent measurements indicated that the density of the invasive soybean aphid, *Aphis glycines*, also was greater on plants grown under elevated $CO_2$. Increased herbivory by the Japanese beetle was associated with a substantial increase in the sugar content of plants grown under elevated $CO_2$ (Fig. 1), because simple sugars are strong feeding stimulants for Japanese beetle.

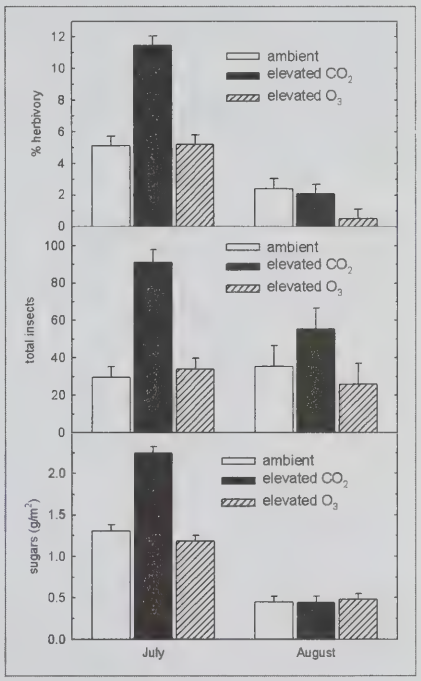


**Figure 1.** Responses of soybean and insect herbivores to elevated $CO_2$ and $O_3$. (A) Leaf tissue (%) consumed by insect herbivores. (B) Insect populations. (C) Leaf sugar concentrations. Sugar content was calculated as the sum of glucose, fructose, and sucrose. Data show mean ± SE. In July, values for the elevated $CO_2$ were significantly greater than ambient or elevated $O_3$ ($P \leq 0.05$).

When given a choice under controlled conditions, Japanese beetles consistently moved to and selectively fed on leaves harvested from plants grown under elevated $CO_2$. In addition to preferring high $CO_2$ leaves, female adult beetles laid more eggs and male and female beetles lived longer when fed elevated $CO_2$ foliage in a laboratory bioassay (Fig. 2). Moreover, because total egg production was positively correlated with the total number of days that both males and females were alive in a cage ($r = 0.490$, $P = 0.008$, $n = 28$), increased fecundity was largely attributable to this longer life span. Feeding on leaves with artificially elevated sugar content did not increase the longevity of

male or female beetles (Fig. 2), but it may have increased fecundity. It seems that changes in leaf chemistry other than simply increased sugar content affects beetle fecundity.

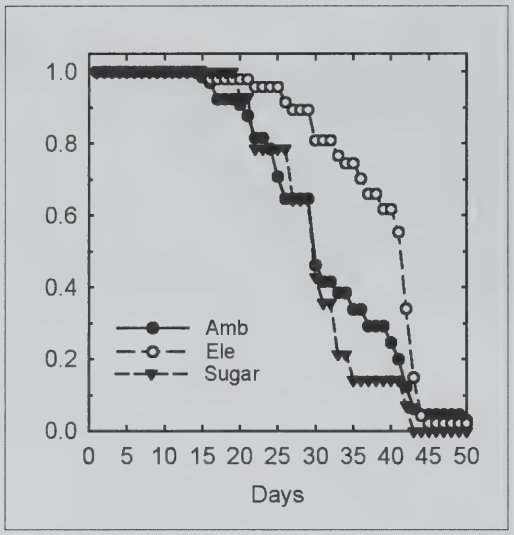


**Figure 2.** Survivorship of male Japanese beetles fed on foliage grown under ambient (Amb) and elevated $CO_2$ (Ele), and foliage grown under ambient $CO_2$ but fed sucrose (sugar) through the transpiration stream. The pattern of survivorship for female beetles was similar.

Preliminary data indicate that soybean cultivars may be differentially susceptible to herbivory under elevated $CO_2$ and $O_3$ (Fig. 3). Half of each plot in the SoyFACE experiment is planted in Pioneer 93B15, a cultivar commonly planted in east central Illinois, whereas the other half of each plot is planted in 1.9-$m^2$ subplots containing 22 different soybean genotypes provided by the USDA Soybean/Maize Germplasm, Pathology, and Genetics Research Unit at the University of Illinois. Cultivars were selected for variation in date of origin and responsiveness to elevated $CO_2$ and $O_3$. In 2003, we made preliminary measurements on 10 of 22 soybean genotypes of the numbers of three common insects, Japanese beetle, corn rootworm (*Diabrotica* spp.), and potato leafhopper (*Empoasca fabae*), to determine whether cultivars are differentially susceptible to herbivory when exposed to two major components of global change. Although our replicate size was low, a three-way analysis of variance (ANOVA) revealed highly significant differences among cultivars in total number of insects ($P < 0.01$), and combining all cultivars, more insects were found in the high $CO_2$ plots than the others ($P = 0.02$). There was no statistically significant cultivar by $O_3$ by $CO_2$ interaction. However, a comparison of the two cultivars with greatest (Corsoy, white bars) and smallest (L600-631, black bars) insect populations revealed a marginally significant $CO_2$ by cultivar interaction ($P = 0.08$). These measurements were made only once during a year in which insect populations were low; a more aggressive and complete sampling effort should reveal strong differences in the effects of elevated $CO_2$ and $O_3$ on insect damage among different soybean genotypes.

Soybean constitutes approximately 25% of all planted agricultural acreage in the United States. In 2001, almost 75 million acres was planted, with Iowa and Illinois producing approximately one-third of the total U.S. crop. Soybean is the leading crop in terms of exports, totaling more than $6 billion in 1999[2] and accounting for one-half of the world's soy production. More than 700 species of herbivorous insects are known

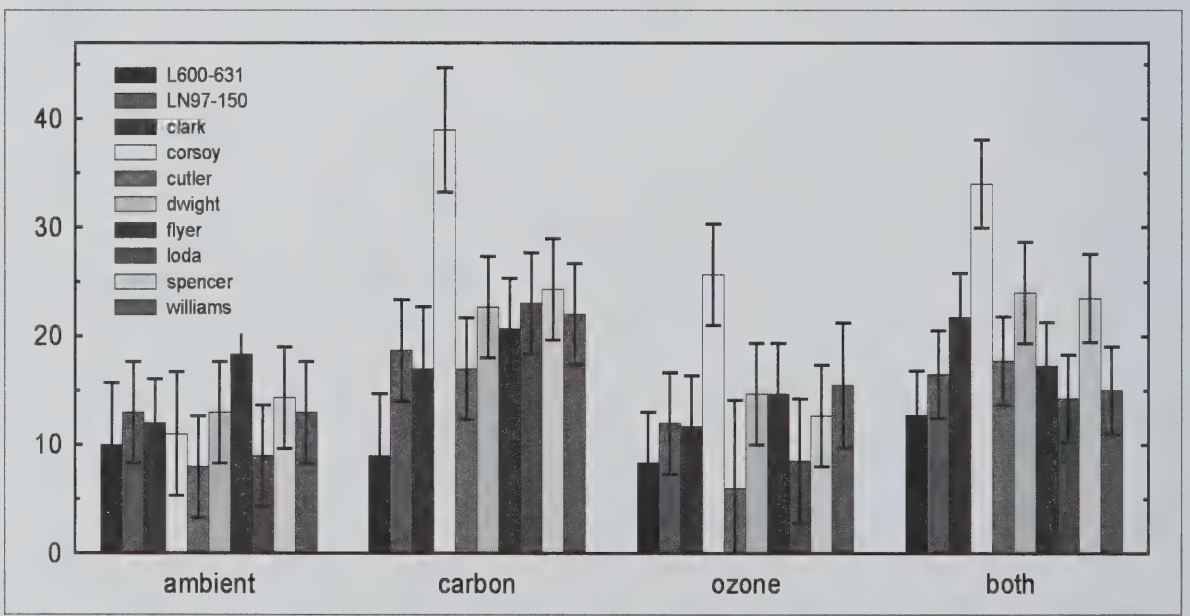


**Figure 3.** Total number of insects harvested from 1.9-$m^2$ plots of 10 different soybean cultivars. Insects were almost entirely comprised of three species: corn rootworm (*Diabrotica* complex), Japanese beetle, and potato leafhopper. Each bar represents a least squares mean of three ambient plots, 3 +$CO_2$ (carbon) plots, 2 +$O_3$ (ozone) plots, and 4 +$CO_2$ +$O_3$ plots (both) ± 1 SE. Insects were sampled over a 4-h period in August 2003.

to consume soybean in the United States. Although in the Midwest soybean historically has rarely experienced serious insect problems, this may be changing with the introduction of invasive insects, including Japanese beetle and soybean aphid. Because acreage is so extensive in the Midwest, when problems occur, losses can be devastating.

Our data suggest that global change in the form of elevated levels of $CO_2$ and $O_3$ may exacerbate pest problems and that changes in tropospheric chemistry alter key aspects of leaf chemistry that affect the feeding and demographic performance of insects, thereby modulating crop damage by insect herbivores. Associated with this increased potential damage will be increased need for sustainable management techniques. A deeper understanding of the mechanisms and genetic variation contributing the susceptibility to herbivory

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[1] http://www.soyface.uiuc.edu/.

[2] http://www.unitedsoybean.org/soystats2000/ page_02.htm.

[3] This research was support by funds from the USDA National Research Initiative; the Illinois council for Food and Agricultural Research (C-FAR) and the Archer Daniels Midland Company support the SoyFACE facility.

# Historical Viewpoint and Soybean Resistance to Soybean Rust

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## Introduction

Soybean rust is caused by two fungal species, *Phakopsora meibomiae* and *P. pachyrhizi*. The Asian soybean rust pathogen, *P. pachyrhizi*, is the species of greater concern because it is the more aggressive species and has been identified in new geographical locations beyond Asia. *P. meibomiae*, the less virulent species, has only been found in the Western hemisphere, and it is not known to cause severe yield losses in soybean (Sinclair and Hartman 1999). Soybean rust is one of the major diseases of soybean in many Asian countries (Sinclair and Hartman 1999) and now in Brazil, since its recent introduction in 2001 (Yorinori et al. 2003). Significant yield losses due to rust have been reported in most soybean-producing countries throughout Asia, where the disease is endemic and may limit soybean production. North America is one of the last major soybean production area without soybean rust.

In Africa, the distribution of soybean rust was not well known before 1996; since then, soybean rust has been found in Uganda, Kenya, and Rwanda in 1996; in Zambia and Zimbabwe in 1998; Nigeria in 1999; Mozambique in 2000; and South Africa in 2001 (Levy 2003).

The first detection of *P. pachyrhizi* in South America was in Paraguay in the 2000–2001 growing season (Yorinori et al. 2003). The disease was found on soybean grown in the Parana River basin on the eastern border with Brazil in a limited number of fields. Argentina confirmed the occurrence of soybean rust in early 2002 (Rossi 2003). During the 2003 growing season, the pathogen was found in most of the soybean-growing regions of Brazil and came late in the season for the first report in Bolivia (Yorinori et al. 2003).

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Trade and manufacturers' names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of others that may also be suitable.

*P. pachyrhizi* infects more than 95 species of plants from more than 42 genera, including soybean and related *Glycine* species (Rytter et al. 1984, Ono et al. 1992). Species that serve as hosts for *P. pachyrhizi* include many of the wild and edible legumes and kudzu, an exotic weed that is widespread in the United States and that could serve as an inoculum reservoir or bridge host for *P. pachyrhizi* in most parts of the southern United States during the temperate months in the north. Such a broad host range is unusual among rust pathogens; most rust species have a narrow host range that is limited to a few plant species. The large number of host species that *P. pachyrhizi* infects increases the likelihood that this pathogen will survive and overwinter in the southern United States as well as the Caribbean Islands and Central America.

## Specific Resistance and Physiological Specialization of the Pathogen

Specific resistance to *P. pachyrhizi* has been described as four single dominant genes (*Rpp1*, *Rpp2*, *Rpp3*, and *Rpp4*) reviewed by Hartwig (1995) and summarized by Miles et al. (2003a) (Table 1). These four genes condition resistance to a limited set of rust isolates. The *Rpp1* was described as having an immune reaction when inoculated with a few isolates, including India 73-1. Inoculation of some rust isolates on *Rpp1* or the other genes produces a resistant red-brown (RB) lesion with no or sparsely sporulating uredinia instead of the susceptible-type reaction (TAN lesion type) (Fig. 1). There are numerous examples of single gene resistance not being durable (Miles et al. 2003a).

Much of the early research on soybean rust was done in some countries in Asia, where the disease was of great concern. In Taiwan, from the 1960s until the early 1990s, research on soybean rust focused on epidemiology and resistance ( Hartman et al. 1991, Hartman 1995). There was a very active field program and many soybean accessions were screened for resistance. It was from these early screens that the first sources of resistance were identified. Soon after that, the first physiological races of *P. pachyrhizi*

were first described when a set of nine single urediniospore isolates were inoculated onto six soybean and five legume accessions (Lin 1966). The reactions of the nine isolates were similar on all six of the soybean genotypes, but six pathotypes were identified based upon their reactions on the legume accessions. The first example of virulence diversity on soybean cultivars was described in Queensland, Australia, (McLean and Byth, 1976) where one rust isolate was found to be virulent on the cultivar 'Willis' but avirulent on the accession PI 200492, whereas another isolate was virulent on both soybean genotypes. Several other studies also have shown considerable variation in virulence among isolates from the same field as well as isolates collected from wide geographical areas (Poonpolgul and Surin 1985, Shin and Tschanz 1986). Use of single genes to control rust may have some utility and may be more promising if the right combination of genes are stacked, but other options such as partial resistance may be needed to develop "slow-rusting" cultivars.

**Table 1.** Named single genes, original sources and *P. pachyrhizi* isolates used in studies of the inheritance of resistance to soybean rust (from Miles et al. 2003a).

| Named single gene | Accession no. and cultivar name of original source | *P. pachyrhizi* Isolates[1] | |
|---|---|---|---|
| | | Resistant reaction | Susceptible reaction |
| $Rpp_1$ | PI200492 | IN 73-I[2,3] | TW 72-1,TW 80-2 |
| | Komata | | |
| $Rpp_2$ | PI230970 | AU 72-I[3], IN 73-I[3], | TW 80-2 |
| | | PH 77-I[3],TW 72-I[3] | |
| $Rpp_3$ | PI462312 | IN 73-I[3] | TW 72-1,TW 80-2 |
| | Ankur | | |
| $Rpp_4$ | PI459025 | IN 73-I[3],TW 72-I[3], | |
| | Bing Nan | TW 80-2[3] | |

[1]AU, Australia; IN, India; PH, Philippines; TW, Taiwan.
[2]Immune reaction type.
[3]Isolates used in original inheritance studies to examine segregation patterns.

Much of the research on differentiating isolates on soybean has been done in the containment facility at Fort Detrick, Frederick, MD. Melching et al. (1979) used four isolates to compare their ability to colonize and reproduce on 'Wayne'. All isolates required a similar time from inoculation to lesion appearance (7 days) and initiation of urediniospore production (9 days). The Indian culture produced more lesions per unit leaf area per inoculum unit than the others. Urediniospores were collected daily 13 to 52 days after inoculation and the calculated total number of spores produced over the life of the lesion was 2,028, 3,768, 6,268, and 6,600 for the Australian, Indian, Indonesian, and the Taiwanese isolates, respectively.

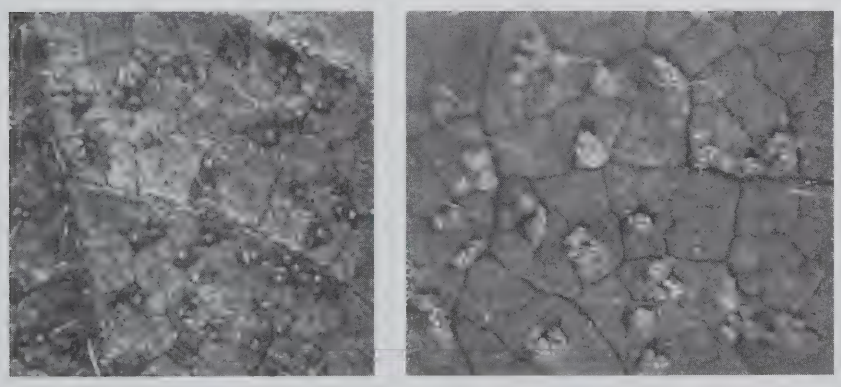

**Figure 1.** Soybean leaves infected by *Phakopsora pachyrhizi* on a (left) susceptible soybean with susceptible (TAN) lesions and (right) red brown (RB type) lesions.

Based on the studies mentioned in this report and many others in the literature, it seems that most isolates of *P. pachyrhizi* possess multiple genes for virulence and field populations are a mixture of many races that may have multiple complex virulent factors. In recent studies done at Fort Detrick, isolates of from southern Africa and South America were significantly more virulent on soybean cultivars containing the single resistance genes compared with the Asian isolates from the 1970s (Table 2). The most virulent isolate was collected from Zimbabwe in 2001.

## Partial Resistance

Partial resistance, or rate-reducing resistance, is also known in soybean (Wang and Hartman 1992). Lines with partial resistance in field evaluations are rated as moderately resistant, because fewer lesions develop on plants throughout the season (Table 3). In greenhouse studies, host–pathogen combinations that resulted in RB reaction types tended to have longer latent periods, lower rates of increase in pustule number over time, and smaller lesions compared with susceptible interactions that resulted in a TAN reaction type (Marchetti et al. 1975, Bromfield and Hartwig 1980). Identification and use of partial resistance in breeding programs has been limited. The evaluation methods may be time-consuming and difficult to incorporate into breeding programs and therefore limited to use with advanced generations. These diffi-

**Table 2.** Reaction of soybean entries challenged with P. pachyrhizi and *P. meibomiae* (Pm) isolates from different countries in the world

| | *P. pachyrhizi* | | | | | | | | | | *Pm* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Entry | TW | TH | PH | ZM | SA | BZ | PG | AU | IN | HW | BZ | PR |
| Williams | S | S | S | S | S | S | S | S | S | S | R | R |
| PI548628 (Wayne) | S | S | S | S | S | S | S | S | S | S | R | R |
| PI200492 (Rpp1) | S | S | S | S | S | S | S | I | I | R | R | R |
| PI230970 (Rpp2) | R | M | R | M | M | M | M | R | M | R | I | R |
| PI462312 (Rpp3-Ankur) | S | S | S | S | R | M | M | R | R | R | I | R |
| PI459025B (Rpp4) | M | R | R | M | M | M | R | S | M | R | R | R |
| PI268039 (Tainung #4) | S | S | M | S | R | M | M | I | I | I | I | R |

TW, Taiwan; TH, Thailand; PH, Philippines; ZM, Zimbabwe; SA, South America; BZ, Brazil; PG, Paraguay; AU, Australia; IN, India; and HW, Hawaii.

S, susceptible (TAN reaction type); R, resistant (RB or red-brown reaction type); M, mixed or intermediate; and I, no reaction.

culties, at least in part, led to the development of a strategy to select genotypes with what was defined as tolerance or yield stability, despite being heavily infected with P. pachyrhizi (Wang and Hartman 1992, Hartman 1995).

## Yield Stability

Yield stability, or tolerance, refers to the strategy of selecting genotypes with high yield potential and less yield loss from soybean rust. Screening for yield stability to soybean rust was started at the Asian Vegetable Research and Development Center (Hartman 1995), where yields from paired plots, with and without the fungicide Dithane M-45 applied every 2 weeks, were compared for losses due to rust (Table 4). High-yielding genotypes with lower yield loss under severe rust conditions were considered to be tolerant. Rust development rates and estimates of rust severity on foliage were not correlated with yield loss in tolerant materials. Using fungicide protected plots as yield checks, tolerant lines from breeding populations were identified without having to take notes on rust severity (Hartman 1995). Cultivars with yield stability may have some partial resistance that was not characterized or selected for in the breeding program.

## Current Research

Since the report of soybean rust in Hawaii in 1994, the USDA–ARS has renewed its support for soybean rust research in the United States. The USDA–ARS containment facility at Ft. Detrick is the focal point of this research and includes collaborators from several states with additional support coming from the United Soybean Board. Part of the research focus has been to identify resistant germplasm. There are more than 16,000 soybean accessions in the USDA Germplasm Collection located at the University of Illinois. These soybean accessions, along with commercial and public cultivars grown in the United States, have been evaluated for resistance to *P. pachyrhizi* in the USDA–ARS Biosafety Level 3 Containment Greenhouses at Fort Detrick. The germplasm evaluations are done on seedlings using a mixture of isolates from Africa, Asia, and South America. More than 16,000 soybean accessions have been screened to date. There are approximately 700 that are of interest as potential sources of resistance. None of the U.S. commercial cultivars evaluated were found to be resistant to the mixture of isolates and they range in susceptibility from moderate to highly susceptible. The soybean accessions showing some level of resistance are being further evaluated using individual iso-

**Table 3.** Yield of 12 soybean lines in fungicide-protected plots and in rust-inoculated plots, and their losses inoculated with *P. pachyrhizi* at the Asian Vegetable Research and Development Center in Taiwan (from Hartman 1995)

| | Yield (kg/ha) | | |
|---|---|---|---|
| Line | Fungicide-protected | Rust-inoculate | Loss (%) |
| AGC 129 | 2,800 | 837 | 70 |
| AGC 181 | 2,279 | 766 | 66 |
| AGC 302 | 2,400 | 1050 | 57 |
| GC 81118-8-4 | 2,816 | 471 | 83 |
| GC 82345-20-2 | 2,864 | 726 | 75 |
| GC 82349-6-1 | 3,440 | 837 | 76 |
| KS 8 | 3,498 | 528 | 85 |
| SRE B-15A | 2,386 | 1,076 | 54 |
| SRE C-56A | 2,567 | 1,818 | 29 |
| SRE C-56e | 2,656 | 1,804 | 31 |
| SRE D-14C | 2,804 | 1,514 | 46 |
| SRE D-14D | 2,605 | 1,502 | 41 |
| FLSD ($P \leq 0.05$)[1] | | | 9 |
| FLSD ($P \leq 0.05$)[2] | | 214 | |
| FLSD ($P \leq 0.05$)[3] | | 263 | |

[1] Differences between main plot means.
[2] Differences between subplots within the same main plot.
[3] Differences between subplots with different main plots.

lates to characterize race-specific and/or partial resistance. These accessions also have been planted in field trials in Brazil, Paraguay, China, Thailand, South Africa, and Zimbabwe for evaluation of adult plant resistance. Additional research is being conducted to determine the best way to evaluate partial resistance and yield stability. Besides soybean, about 1,000 *Glycine soja* accessions have or will be screened along with some of the perennial *Glycine* spp. previously reported as having resistance (Hartman et al. 1992). As sources of resistance are identified, crosses will be made to incorporate these resistance traits into adapted backgrounds for commercial use.

**Table 4.** Yield and 100 seed weight in fungicide-protected plots and in rust-inoculated plots, and their losses on 12 soybean lines inoculated with *P. pachyrhizi* (from Hartman 1995)

| Line | Yield (kg/ha) | | | 100-seed weight (g) | | |
|---|---|---|---|---|---|---|
| | Fungicide-protected | Rust-inoculate | Loss (%) | Fungicide-protected | Rust-inoculated | Loss (%) |
| **AGC 129** | **2800** | **837** | **70** | **16.1** | **7.5** | **53** |
| AGC 181 | 2279 | 766 | 66 | 17.1 | 10.0 | 42 |
| AGC 302 | 2400 | 1050 | 57 | 21.2 | 12.5 | 41 |
| GC 81118-8-4 | 2816 | 471 | 83 | 17.3 | 6.2 | 64 |
| GC 82345-20-2 | 2864 | 726 | 75 | 19.5 | 7.8 | 59 |
| GC 82349-6-1 | 3440 | 837 | 76 | 22.5 | 14.3 | 36 |
| KS 8 | 3498 | 528 | 85 | 29.8 | 11.1 | 63 |
| SRE B-15A | 2386 | 1076 | 54 | 17.4 | 10.4 | 40 |
| SRE C-56A | 2567 | 1818 | 29 | 25.5 | 18.0 | 29 |
| SRE C-56e | 2656 | 1804 | 31 | 20.7 | 13.6 | 34 |
| SRE D-14C | 2804 | 1514 | 46 | 23.5 | 16.6 | 29 |
| SRE D-14D | 2605 | 1502 | 41 | 25.0 | 16.4 | 34 |
| FLSD ($P \leq 0.05$)[1] | | | 9 | | | 8 |
| FLSD ($P \leq 0.05$)[2] | | 214 | | | 2.0 | |
| FLSD ($P \leq 0.05$)[3] | | 263 | | | 2.3 | |

[1] Differences between main plot means.
[2] Differences between subplots within the same main plot.
[3] Differences between subplots with different main plots.

## Future Management of Soybean Rust

Control of soybean rust can be accomplished through use of fungicides (Miles et al. 2003b). Once commercial U.S. cultivars are fully evaluated in the field, there will be a list of highly susceptible cultivars that growers should not plant. Single gene resistance may or may not be part of the overall strategy for control, although single genes are easy to work with in a backcrossing program because desirable traits can be moved into elite breeding stock in a relatively short time period. In this particular case, *P. pachyrhizi* may easily overcome any single gene resistance. It may be possible that the right combination of single genes will be useful in a resistance management program. Partial resistance also may contribute to the control of soybean rust in that it will slow down the epidemic, thereby decreasing the buildup of rust spores. Fewer spores produced over time could effectively reduce the need for multiple fungicide applications.

Yield stability, with or without single, stacked, or partial resistance also may be effective in reducing potential yield losses. Cultivars that show some level of yield stability will be identified. Dealing with yield stability in a breeding program may not be an easy task because it will require that later generation material be evaluated by comparing yields of plants in plots with rust to plants in plots sprayed with a fungicide to control rust so that percentages of yield among lines based on the control plots can be compared. Each season in the United States without rust provides additional time to evaluate and register fungicides and to test and incorporate resistance and/or yield stability into more adaptable soybean breeding lines.

## Acknowledgements

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## References

Hartman, G.L. 1995. Highlights of soybean rust research at the Asian Vegetable Research and Development Center, pp. 19-28, in J.B. Sinclair and G.L. Hartman (eds), Proceedings of the Soybean Rust Workshop, 9–11 August 1995, vol. 1. College of Agricultural, Consumer, and Environmental Sciences, National Soybean Research Laboratory, Urbana, IL.

Hartman, G.L., T.C. Wang, and A.T. Tschanz. 1991. Soybean rust development and the quantitative relationship between rust severity and soybean yield. Plant Disease 75: 596–600.

Hartwig, E.E. 1995. Resistance to soybean rust, in J. B. Sinclair and G. L. Hartman (eds), Proceedings of the Soybean Rust Workshop, 9–11 August 1995. College of Agricultural,

Consumer and Environmental Sciences, National Soybean Research Laboratory, Urbana, IL.

Levy, C. 2003. Measures to control soybean rust in Southern Africa and an initial investigation of the meteorological factors that favor its development. (Abstr.) Phytopathology 93: S103.

Lin, S.Y. 1966. Studies on the physiologic races of soybean rust fungus, *Phakopsora pachyrhizi* Syd. Journal of Taiwan Agricultural Research 15: 24–28.

McLean, R., and D.E. Byth. 1976. Resistance of soybean to rust in Australia. APPS Newsletter 5: 34–36.

Miles, M.R., R.D. Frederick, and G.L. Hartman. 2003a. Soybean rust: is the U.S. crop at risk? http://www.apsnet.org/online/feature/rust/ (verified 150029).

Miles, M.R., G.L. Hartman, C. Levy, and W. Morel. 2003b. Current status of soybean rust control by fungicides. Pesticide Outlook 14: 197–200.

Ono, Y., P. Buritica, and J.F. Hennen. 1992. Delimitation of *Phakopsora, Physopella* and *Cerotelium* and their species on *Leguminosae*. Mycology Research 96: 825–850.

Poonpolgul, S., and P. Surin. 1985. Physiological races of soybean rust in Thailand. Thai Phytopathology 5: 119–120.

Rossi, R.L. 2003. First report of Phakopsora pachyrhizi, the causal organism of soybean rust in the province of Misiones, Argentina. Plant Disease 87: 102.

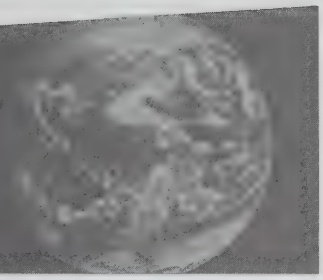
Rytter, J.L., W.M. Dowler, and K.R. Bromfield. 1984. Additional alternative hosts of *Phakopsora pachyrhizi*, causal agent of soybean rust. Plant Disease 68: 818–819.

Shin, D.C., and A.T. Tschanz. 1986. Studies on physiological reactions of soybean cultivars tolerant and susceptible to rust (*Phakopsora pachyrhizi* Syd.). Korean Journal of Crop Science 31: 440–446.

Wang, T.C., and G.L. Hartman. 1992. Epidemiology of soybean rust and breeding for host resistance. Plant Protection Bulletin Taipei 34: 109–124.

Yorinori, J.T., W.M. Paiva, R.D. Frederick, L.M. Costamilan, P.F. Bertagnolli, G.L. Hartman, C.V. Godoy, and J.J. Nunes. 2003. Epidemics of soybean rust (*Phakopsora pachyrhizi*) in Brazil and Paraguay from 2001 to 2003. (Abstr.) Phytopathology 93: S103.

# Models and Dispersal for Asian Soybean Rust



*Roger Magarey and Scott A. Isard*

The USDA–Animal and Plant Health Inspection Service (APHIS) is preparing for the entry of soybean rust, *Phakopsora pachyrhizi*, in the contiguous United States. The belief is that aerial transport to the United States is a probable pathway for the initial entry of soybean rust and that the likelihood of aerial dispersal to our country will increase as the pathogen expands its range towards North America. In response to this threat USDA–APHIS is funding a multiyear project to examine the aerial transport pathway. The project is a joint effort between USDA–APHIS, North Carolina State University, Pennsylvania State University, and the information technology company ZedX. Contributions by Monte Miles and Glen Hartman (ARS, Illinois) have been critical to the success of this interdisciplinary project.

The first year of the project, produced four deliverables as described in a comprehensive report (Isard et al. 2004).

1) A Web site (soybeanrust.zedxinc.com) through which APHIS is providing stakeholders with information on the aerial dispersal of soybean rust.

2) Maps of soybean rust source areas in Africa and South America.

3) Simulations of aerial soybean rust dispersal into South and North America using the HYSPLIT atmospheric transport model.

4) Simulations of aerial soybean rust dispersal into South and North America by using the newly developed Integrated Aerobiology Modeling System framework. The report also includes information to support risk assessments of aerial incursion of soybean rust into the United States.

The most important findings of the research project during 2004 are the following.

1) Opportunities for aerial transport of *P. pachyrhizi* spores from infested soybean-growing areas in eastern Asia to Hawaii in 1994 and from southern and western Africa to South America in 2001 existed 1 to 2 months before the first discovery of soybean rust epidemics in these regions. Airborne spores would have had to remain viable for 1 to 2 weeks to have caused the new infestations.

2) There is a substantially higher risk of aerial transport of *P. pachyrhizi* spores to the United States from the current infestation region in South America than from Africa.

3) The risk of a soybean rust epidemic in the United States due to aerial transport of *P. pachyrhizi* spores from south of the equator in South America is low.

4) If the pathogen has spread into soybean-growing regions north of the equator in South America, then the risk of soybean rust incursion into the United States during 2004 has increased. Presence of soybean rust north of the equator has now been confirmed in Cali, Colombia.

5) Once soybean rust epidemics occur in the northern South American soybean-growing region, winds will likely transport the spores within the Intertropical Convergence Zone (ITCZ) to Central America during the same growing season.

6) Tropical cyclones have the potential to transport *P. pachyrhizi* spores from the northern South American soybean-growing region directly into the southern United States. However, heavy precipitation associated with these storms makes this event unlikely. Subsequent analysis of trajectories during the 2004 tropical storm season did not reveal any likely candidates for direct spore transport to the United States (Keever and Magarey, unpublished data).

7) In the event that *P. pachyrhizi* becomes well established around the Caribbean/Gulf of Mexico basin, aerial transport of soybean rust spores into the continental interior of North America is likely to occur each spring.

As part of this effort, project staff cooperated with USDA–ARS personnel to provide a risk assessment of soybean rust threat to agricultural production regions. The analysis was based upon source strength, aerial transport, host strength, and epidemic potential by using known source areas in South America. The risk of rust incursion was greatest in June and July, whereas August and September also had an elevated risk level. The Appalachia (Mid-Atlantic states) region had an almost two-fold greater risk than the Corn Belt and a three-fold greater risk than the southeastern region. With the recent range expansion of soybean rust into northwestern South America, the relative risks associated incursion for the U.S. agricultural regions have changed.

It is anticipated that APHIS will renew funding of the project in 2005. Beginning in early spring of 2005, near real-time daily risk maps will be created to track spore transport from known source areas to Central America and North America, including the Caribbean. These maps will be placed on the Web and summarized weekly and monthly with an accumulated risk index for U.S. agricultural regions.

## References

Isard, S.A., C. Main, T. Keever, R. Magarey, S. Redlin, and J. M. Russo. 2004. Weather-based assessment of soybean rust threat to North America. Final report to APHIS. http://www.aphis.usda.gov/ppq/ep/soybean_rust/.

# Management of Asian Soybean Rust

*Monte R. Miles, Glen L. Hartman, and Reid D. Frederick*

## Introduction

The identification of Asian soybean rust in Paraguay in 2001 (Morel and Yorinori 2002) and its spread to more than 95% of the soybean production in Brazil through the 2004 growing season has heightened the awareness of this disease worldwide. The rapid spread of *Phakopsora pachyrhizi* and the potential for severe yield losses makes this the most destructive foliar disease of soybean. Yield losses of 20 to 60% were reported in Asia with losses of 80% reported from experimental fields in Taiwan (Hartman et al. 1992). Yield losses of 40 to 60% were reported in southern Africa with reports of 100% loss in individual fields (Caldwell et al. 2001). During the 2003–2004 growing season in Brazil, yield losses were estimated at 10% of the annual crop, an increase from the 5% yield loss estimate reported for the 2002–2003 growing season (Yorinori, personal communication). Soybean rust, if introduced into the United States, could have a major impact on both total soybean production and production costs.

In the near future, the primary tool to control soybean rust will be fungicides (Miles et al. 2003a). Fungicides have been used effectively in southern Africa and South America to manage the disease. Cultural practices have not been shown to be effective in controlling the pathogen; recommendations were inconsistent and varied by location. The most effective cultural practices were those that maximized yields in the absence of the disease or planting during seasons when the disease could be avoided. Incorporation of resistance into commercial cultivars is several years away and will be made more difficult by the need to use nonrace specific resistance.

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Trade and manufacturers' names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of others that may also be suitable.

## Fungicide Efficacy

Many fungicides have been evaluated to control soybean rust. Early research from Asia indicated that mancozeb was effective (Hartman et al. 1992). Other compounds available at the time were compared with mancozeb and were effective, but results varied by test (Miles et al. 2003b). Fungicide trials in India (Patil and Anahosur 1998) and southern Africa (Levy 2004) identified several triazole compounds and triazole mixes that controlled soybean rust. More recent trials in Africa and South America have identified additional triazoles, tebuconazole and tetraconazole, as well as several strobilurins and strobilurin mixes, including, azoxystrobin, pyraclostrobin, pyraclostrobin + boscalid, and trifloxystrobin + propiconazole (Miles et al. 2003c). Additional triazoles are commercially available in Brazil; among these are epoxiconazole, cyproconazole, and metconazole. These fungicides have been shown to be very effective when mixed with one of the strobilurin compounds.

## Labeled and Section 18 Compounds

There are three fungicides that are registered for use on soybean, labeled for soybean rust, and are commercially available in the United States (Table 1). These fungicides are Bravo®, Echo®, and Quadris®. Quadris® is an azoxystrobin; Bravo and Echo are both chlorothalonil products. There has been a Section 18 Emergency Exemption request for seven compounds or mixtures of compounds submitted to the Environmental Prection Agency (EPA) by the Departments of Agriculture of Minnesota and South Dakota (http://plantsci.sdstate.edu/draperm/SoybeanRustSection18). At least 24 other soybean-producing states have followed with requests of their own. Not included on any of the lists are the sulfur, lime, elemental compounds, various oils, and other organic products that may not be viable management tools in large commercial operations.

The fungicides that will be available for managing soybean rust fit into three classes: chlorothalonil, strobilurin, and triazole. The strobilurins and triazoles have single site mode

of actions. The strobilurins bind to the cytochrome in the mitochondria, which interferes with respiration, preventing spore germination and fungal growth. The triazole fungicides are sterol inhibitors, interfering with sterol biosynthesis in fungal membranes. Both strobilurins and triazoles are absorbed into leaf tissue and translocate within the leaf tissue. The triazoles move rapidly through the leaf and can be dissipated in as little as 10 days, depending on application rate. The strobilurin fungicides translocate much slower, giving them a longer residual period. Chlorothalonil products have multiple modes of action but are limited in having a longer (41 day) preharvest interval versus the 14-day preharvest interval of most other products. The chlorothalonil products are not absorbed into the plant tissue, as are the strobilurins and triazoles, but remain on the leaf surface where they are active. Within each of the fungicide classes the products differ in yield protection, translocation ability, and residual activity.

**Table 1. Fungicides registered for use on soybean, labeled for Asian soybean rust or on a Section 18 Emergency Exemption request.**

| Compound | Product | Company | Registration status | |
|---|---|---|---|---|
| | | | Soybeans | Soybean rust |
| Azoxystrobin | Quadris® | Syngenta | Yes | Labeled |
| Chlorothalonil | Bravo® | Syngenta | Yes | Labeled |
| | Echo® | Sipcam Agro | Yes | |
| Myclobutanil | Laredo® | DAS | | Section 18[a] Approved 4/04 |
| Propiconazole | Tilt® | Syngenta | | Section 18[a] Approved 4/04 |
| | Propimax® | DAS | | |
| | Bumper® | Makhteshim-Agan | | |
| Pyraclostrobin | Headline ® | BASF | | Section 18[a] |
| Pyraclostrobin + boscalid | Pristine ® | BASF | (Yes[b]) | Section 18[a] |
| Tebuconazole | Folicur® | Bayer | | Section 18[a] Approved 8/04 |
| Tetraconazole | Eminent® | Sipcam Agro | | Section 18[a] |
| Trifloxystrobin + propiconazole | Stratego® | Bayer | | Section 18[a] |

a. http://plantsci.sdstate.edu/draperm/SoybeanRustSection18

b. Boscalid has been registered for use on soybean, but will not be labled for use against soybean rust.

## Timing and Number of Applications

The most recent experiments evaluating the timing and number of applications for chemical control of soybean rust have come from Zimbabwe and South Africa (Levy et al. 2002). Early experiments evaluated the number of applications needed to protect the crop. There were no differences in yields when fungicide application started 28 days after planting (DAP) with five applications, or when application started 48 DAP with four applications. There was a slight yield loss when the first treatment was applied 68 DAP, with three applications in the season. Delaying fungicide application until 88 DAP, with two applications, and 108 DAP, with a single late application, resulted in significant yield losses. Flowering of the cultivars used in the study started between 50 and 60 DAP. When fungicides were applied during the vegetative growth stages, 28 DAP, yields did not increase compared with applications that protected the crop from flowering through grain fill, 48 and 68 DAP.

Experiments that evaluated the timing of applications in postflowering soybean were completed using 'Sonata' and 'Soprano', treated with 50 g of flusilazole + 100 g of carbendazim (Punch Xtra®) in single applications at either 50, 60, 70, 80, or 90 DAP, and two-application treatments at 50 + 70 DAP, 60 + 80 DAP, or 70 + 90 DAP. A three-application treatment, 50 + 70 + 90 DAP, simulated the recommendation being made to farmers, and a four-application treatment was included to provide total rust control. A single, properly timed application can protect yields compared with treatments with two or more applications (Levy 2004). The timing of the application was critical, because applications 10 days earlier or later showed significant yield losses. All treatments with two applications had yields similar to treatments with three or four applications. Late applications had slightly less protection in 'Soprano', the indeterminate cultivar, compared with the determinant 'Sonata'.

## Recommendations

In southern Africa, the recommendation was made to use a program with two or three fungicide applications (Levy 2004). Three applications were considered necessary in high disease situations, whereas two applications were recommended when disease severities were light. For best yield protection the first application was recommended at 50 DAP, at or just ahead of flowering. Subsequent applications 20 days apart were sufficient to control the disease. These recommendations were made in an attempt to limit the exposure of the crop to the disease due to difficulties in obtaining exact timing of a single application. This recommendation was supported by limited data from Paraguay where a single application at flowering had less yield protection than two applications, one at flowering followed by another 20 days later (Miles, unpublished data).

The production practices in Brazil are changing from a single late fungicide application (growth stage R5), used to

| Table 2. Comparison properties of protectant and curative fungicides for soybean rust management | |
|---|---|
| **Protectant** | **Curative** |
| May or may not be absorbed into leaf tissue | Adsorbed into leaf tissue |
| May or may not be translocated through leaf tissue. If translocated then moves slowly through tissue | Locally translocated through leaf tissue, usually rapidly |
| Longer period of residual activity | Short residual period |
| Interferes with fungal growth and spore germination | Kills fungal tissue, interferes with respiration |
| Can only be used after infection or when infections are very low, below 3-5% severity | Can be used after infection, most effective when less then 10% severity |
| Chlorothalonil and strobilurin products | Triazole and triazole-strobilurin mixes |

protect against late-season diseases, to a two-application program with the first application at growth stage R3 or earlier. These recommendations differ from the recommendations in southern Africa. As the scenario plays out in South America, we will learn more about the timing and number of fungicides applications to manage soybean rust.

In the United States, recommendations for management of soybean rust will be based on information obtained from southern Africa and South America. The products listed in the Section 18 Emergency Exemption request have been evaluated in common trials Zimbabwe and Paraguay (Miles et al. 2003c, 2004a,b), as well as by individual companies in Brazil. All of the fungicides, registered and labeled for soybean rust, as well as those on the Section 18 Emergency Exemption list, reduced the severity of soybean rust. Among the products, Dithane®, Bravo®, and Echo® reduced soybean rust severities the least. This result is not unexpected. These three fungicides are not absorbed into the leaf but are protectant fungicides that provide control by limiting infection and spore germination on the leaf surface; once an infection occurs these products do not interfere with fungal development. The experimental protocol was to apply fungicides at 20-day intervals; this interval is too long for these products. Labeled recommendations for these fungicides are to apply at 7- to 14-day intervals, depending on rainfall. These products have a place in managing soybean rust, but they will be most effective when applied as labeled.

The triazole and strobilurin fungicides, as well as mixes of the two, were effective in reducing soybean rust severity. However, individual fungicides differ in their strengths. As a class, the triazoles have short residual periods, moving rapidly through the leaf where they are effective in killing the pathogen by interfering with fungal respiration. Under application schedules longer than 14 days, the triazole products may dissipate from the plant tissue, unless high rates are used. The strobilurin products have a longer residual, moving slower through the leaf tissue. However, their mode of action limits spore germination and fungal growth, so they are not as effective in controlling the pathogen once it is established. If infection levels are too high, above 3 to 5% severity, when the strobilurin fungicides are first applied, they may not protect yields. Additional research on the timing of application and rotation of triazoles and strobilurin fungicides is needed. Additional research also needs to be done on the interaction of soybean rust severities at application and subsequent yield loss for each of the different fungicides. Because both the triazoles and strobilurins have a single site mode of action, it is necessary to limit their use to one application per season for each. The relative curative ability of the triazoles and the interaction between application rates and residual effects need to be evaluated.

The development of a management plan using fungicides to minimize losses to soybean rust will not be simple. The exact number of applications will depend on the length of the reproductive phase of the crop, duration of the compound, and severity of the epidemic as well as the econo-

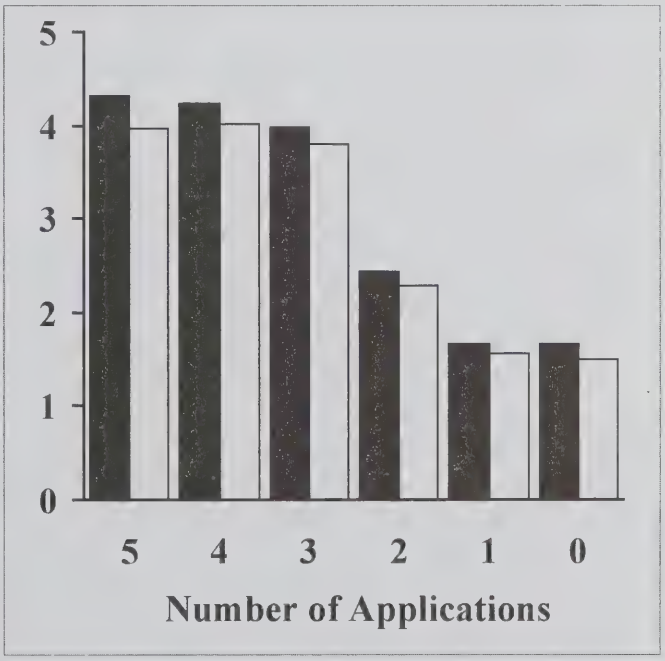


**Figure 1.** Kernel yield (tons ha$^{-1}$, at 11% moisture content) of two soybean cultivars ('Soprano': ■ ; 'Sonata': □ ) either sprayed with flusilazol + carbendazim, or left unsprayed at various dates after planting at the Rattray Arnold Research Station, Enterprise, Zimbabwe, in the 2000–2001 season (from Miles et al. 2003c).

mics of the situation. The number and timing of applications are critical for the control of soybean rust. The most efficient applications were during early reproductive growth, allowing for protection through to crop maturity Fungicide applications in early vegetative stages, although effective in reducing disease severity, have not been shown to be effective in protecting yield. The choice between an application before infection (protective) and an application after infection (curative) also needs to be considered (Table 2). In South America and southern Africa, the most effective management programs have been those where fungicides were used in a protective application before infection. For U.S. producers, the choice of a protective application will allow the use of all products that are labeled for soybean rust control or on the Section 18 Emergency Exemption list. If the first fungicide application is curative or applied after infection, then the choice of product is limited to the triazoles. Strobilurin fungicides have not been effective when used after infection. Yield losses have been observed when soybean rust severity was as low as 3 to 5% before treatment with a strobilurin. However, when disease severity before application was high, above 10%, then yield loss occurred even when a triazole product was used. If more than one fungicide application is needed in the growing season, then resistance management will play a role in choice of product. Both strobilurin and triazole products have a single site mode of action, they can be used only once per season. Repeated application of a single site mode of action may lead to the loss of the product if the pathogen population adapts to the fungicide. A product that is a mixture of a strobilurin and a triazole can be used twice in the same season. These products have the best of both classes of fungicides with the rapid translocation and curative effects of the triazole combined with the slower translocation and long residual of the strobilurin. An additional benefit with mixtures is the reduced risk of resistance to the single site mode or action fungicides developing in the pathogen population. However, this benefit may be lost if product are reduced to a level that will allow the pathogen to adapt. Reducing rates to save cost may allow resistance to be selected in the pathogen population.

**Figure 2.** Kernel yield (tons ha$^{-1}$, at 11% moisture content) of two soybean cultivars ('Soprano': ■ ; 'Sonata': □ ) either sprayed with flusilazol + carbendazim, or left unsprayed at various dates after planting at the Rattray Arnold Research Station, Enterprise, Zimbabwe, in the 2000–2001 season (from Miles et al. 2003c).

## Conclusions

All of the fungicide products that are registered and labeled for soybean rust management or listed on the Section 18 Emergency Exemption request are effective in managing soybean rust. The products are known to differ in both yield protection and reduction of disease severity. There are still many questions to be answered about the use of fungicides to manage soybean rust in the United States. The most effective rotation of products, the return on cost of the fungicide and its application, and the risks associated with pre- or postinfection management strategies still need to be determined. The epidemiology of the pathogen, where it will overwinter, as well as how often and when it will occur in local areas are questions that cannot be answered until after the pathogen becomes established. To reduce the risk of yield loss and unnecessary fungicide applications, a forecast system for soybean rust needs to be developed. The economics of the crop, time and severity of infection, along with the availability of fungicides and equipment needed to apply them will determine the response for individual producers.

## Acknowledgements

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## References

Caldwell, P., M. Laing, and J. Ward. 2002. Soybean rust -- an important new disease on soybeans. Available at http://www.saspp.org/archived_articles/Pat_CaldwellJan2002.php. Accessed 5/5/2004.

Hartman, G. L., E.M. Saddoui, A.T. Tschanz, R. MacIntyre, and K. Lopez. (eds). 1992. Annotated bibliography of soybean rust (*Phakopsora pachyrhizi* Syd.), AVRDC library bibliography series 4-1, Tropical Vegetable Information Service. Taipei: Asian Vegetable Research and Development Center.

Levy, C. 2004. Zimbabwe -- a country report on soybean rust control, pp. 340–348, in Proceedings of VII World Soybean Research Conference, IV International Soybean Processing and Utilization Conference, III Congresso Mundial de Soja (Brazilian Soybean Conference), F. Moscardi, C.B. Hoffman-Campo, O. Ferreira Saraiva, P.R. Galerani, F.C. Krzyzanowski, and M.C. Carrão-Panizzi (eds). Emprapa Soybean, Londrina.

Levy, C., J.S. Techagwa, and J.R. Tattersfield. 2002. The status of soybean rust in Zimbabwe and South Africa. Paper read at Brazilian Soybean Congress, at Foz do Iguaçu, Parana, Brazil.

Miles, M.R., G.L. Hartman, and R.D. Frederick. 2003a. Soybean rust: is the U.S. crop at risk? Available at http://www.apsnet.org/online/feature/rust. Accessed 5/6/2004.

Miles, M.R., C. Levy, and G.L. Hartman. 2004a. Summary of the USDA fungicide efficacy trials to control soybean rust in Zimbabwe 2003-2004. (unpublished).

Miles, M.R., W. Morel, and G.L. Hartman. 2003b. Summary of USDA fungicide trials to control soybean rust in Paraguay 2002-2003. Available at http://www.ipmcenters.org/NewsAlerts/soybeanrust. Accessed 10/72004.

Miles, M.R., W. Morel, T. Steinlage, and G.L. Hartman. 2004b. Summary of USDA fungicide trials to control soybean rust in Paraguay 2003-2004. (unpublished).

Miles, M.R., G.L. Hartman, C. Levy, and W. Morel. 2003c. Current status of soybean rust control by fungicides. Pesticide Outlook 14: 197–200.

Morel, W. and J.T. Yorinori. 2002. Situación de la roya de la soya en el Paraguay. Boletín de divulgación No. 44. Centro Regional de Investigación Agrícola (CRIA), Capitán Miranda, Itapúa, Paraguay.

Patil, P.V. and K.H. Anahosur. 1998. Control of soybean rust by fungicides. Indian Phytopathology 51: 265–268.

# Movement of Western Corn Rootworm Adults Within and Between Fields: Implications for Resistance Management

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## Introduction

Rotation resistance in the western corn rootworm (WCR, *Diabrotica virgifera virgifera*) is a problem with movement at its core (Levine et al. 2002). In the affected areas of Illinois and the surrounding states of Indiana, Ohio, Michigan, and Wisconsin, rotation-resistant adult WCR move frequently between corn, soybean, and other crops where they feed and lay eggs just as they formerly did when their movements were primarily between cornfields. Growers in threatened areas of these states are advised to monitor WCR populations that move from cornfields into soybean and other crops rotated with corn. When WCR trap captures in fields that will be rotated to corn the following year exceed the economic threshold, growers should plan to protect their first-year corn during the following spring. Application of a soil insecticide and planting rootworm-resistant transgenic corn are two effective techniques to manage corn rootworm injury in rotated corn.

Understanding WCR movement and ecology is key not only to developing robust strategies to manage the rotation-resistant population but also to ensure that management tools, such as insecticides and transgenic corn, remain effective. We do well to be wary of the WCR and its rootworm cousins; they have a storied history of developing resistance to a variety of insecticides as well as cultural control (crop rotation) (Metcalf 1983). The recent evolution of WCR behavioral resistance to crop rotation offers an object lesson of what can happen when a highly effective control measure is used broadly without any provision for sufficient refuges to preserve susceptibility. Because crop rotation killed the offspring of WCR that laid eggs in cornfields, its near universal adoption rapidly selected for females that laid eggs in soybean fields. Recent models of the evolution of resistance to crop rotation suggest that if crop rotation had only been used on 80% or less of Illinois cornfields, there would have been enough "rotation-susceptible" adults emerging from continuous corn to mate with beetles from rotated fields and prevent rotation resistance from taking hold. In the years between the 1964 arrival of the WCR in Illinois and the first detection of behavioral resistance to crop rotation in 1987, up to 98% of corn in east central Illinois was rotated (Onstad et al. 2001). The success of crop rotation was very likely its own undoing.

The loss of crop rotation as a reliable and environmentally benign rootworm management strategy led to a dramatic increase in the use of soil insecticides in the eastern Corn Belt. Without crop rotation for rootworm control, growers were forced to fall back on insecticide use; Illinois and Indiana lie at the center of an area with heavy insecticide use in rotated corn. In these two states 58 and 52%, respectively, of corn acres were treated with insecticide in 2003; in Iowa, a state that has yet to encounter the rotation-resistant WCR, only 14% of all corn acres were treated (USDA 2004). Since 2003, producers have had the option of planting rootworm-protected transgenic corn (YieldGard® Rootworm [YGRW], Monsanto Company, St. Louis, MO) that expresses a *Bacillus thuringiensis* (Bt) protein, Cry3Bb1, which kills many WCR larvae before they can develop on corn roots. YGRW offers root protection that is as good or better than that available with soil insecticide application, at a comparable price. Additional transgenic varieties for WCR control are also approaching commercialization. Because management options are limited for producers at the epicenter of rotation resistance, preservation of existing options and wise stewardship of new tools to avoid resistance are especially important.

## Refuges and WCR Movement

The U.S. Environmental Protection Agency (EPA) has declared that the potential for broad-scale resistance to Bt plant-incorporated protectants warrants action to reduce the risk of resistance. To this end, insecticide resistance management (IRM) plans are mandated for all transgenic plant varieties with Bt plant-incorporated protectants. The planting of non-Bt refuges is central to IRM. Refuges provide a large reservoir of Bt-susceptible adult insects that will disperse and randomly mate with potentially Bt-resistant adults emerging from nearby Bt crops. The appropriate

size and placement of the refuge depend on the amount of Bt expressed in the plant, how susceptible the pest is to the Bt protein, and mobility of the target pest. For Bt transgenic corn varieties targeting the very mobile European corn borer, *Ostrinia nubilalis*, a 20% refuge (50% in areas where cotton also is grown) located within 0.5 mile of each Bt cornfield is required (National Corn Growers Association 2001). The IRM plan for YieldGard® Rootworm includes a 20% in-field or adjacent non-Bt refuge (EPA Office of Pesticide Programs 2003). Whether a particular refuge design promotes adequate mating between rootworms from the Bt crop and the non-Bt refuge will depend on how well the relative size and placement of crop and refuge fields are matched to the movement capabilities of WCR adults. An understanding of pest movement is necessary to design a robust refuge strategy. The careful measurement of beetle movement in the field not only contributes to refuge design but also affords us the opportunity to study factors that influence movement patterns that might otherwise go unnoticed.

Numerous studies have examined adult WCR movement capabilities and factors that affect patterns of dispersal at many spatial and temporal scales (Van Woerkom et al. 1980, 1983; Coats et al. 1986, 1987; Grant and Seevers 1989, 1990; Lance et al. 1989; Naranjo 1990a,b, 1991; Isard et al. 1999, 2000; Spencer et al. 1999). Few of these, however, studied field movement in enough detail to be useful to integrated pest management (IPM) practitioners or modelers evaluating IRM design options.

Insect activity data are typically obtained by directly observing insects or using a method known as mark–release–recapture. Many techniques have been used to mark and release individual insects so that they may be identified if later recaptured at another location (reviewed by Hagler and Jackson 2001). Locally, WCR are so abundant that it is difficult to mark enough individuals with traditional methods, such fluorescent powders, to ensure that a reasonable number of marked insects will later be recaptured. Faced with this difficulty, we developed a new method to mark WCR and study their movement that took advantage of transgenic corn and the WCR abundance in local fields.

## Using Transgenic Plants to Monitor Western Corn Rootworm Movement

In 2001, we used simple test strips, designed to verify expression of a Bt protein (Cry3Bb1) in YieldGard® Rootworm to identify WCR that ingested transgenic corn tissue (Spencer et. al. 2003). Unlike larvae, WCR adults are unharmed by eating Cry3Bb1 protein. We found that the probability of detecting ingested Cry3Bb protein declined linearly as time since feeding on YieldGard® Rootworm corn increased. At 24 h since last feeding on YieldGard® Rootworm, no Cry3Bb1-positive WCRs were detected. We set 24 h as the maximum postfeeding time interval for detection of ingested YieldGard® Rootworm tissue in a WCR adult. Beyond the 24-h postfeeding detection interval, excretory processes have flushed the WCR system of any last detectable amounts of Cry3Bb1 protein.

For this study, two adjacent 0.8-acre blocks of nontransgenic rotated crops (soybean and wheat or soybean and double-cropped wheat–soybean) were grown on either side of a central 20-row-wide strip (also 0.8 acre) of YieldGard® Rootworm corn. The rows of corn were parallel to the rows of the rotated crops. There were three replicates of this field arrangement. WCR were collected in these fields during sweep net sampling at 1, 2, 4, 8 16, and 32 rows away from the interface between the YieldGard® Rootworm corn and the rotated crops. The groups of WCR captured at known distances from the YieldGard® Rootworm corn were tested individually for the presence of detectable Cry3Bb1 protein that was ingested as they fed in corn before moving into the rotated crop. Dividing the distance from the edge of the YieldGard® Rootworm corn strip (the only local source of Cry3Bb1 protein) to the collection point for each insect that tested positive for Cry3Bb1 by the postfeeding detection interval, 24 h, we were able to calculate interfield WCR movement rates from transgenic corn to soybean, wheat, and double-cropped wheat–soybean. Likewise, strips of YieldGard® Rootworm corn planted in larger fields of nontransgenic corn allowed us to measure intrafield WCR movement rates by using the same method. Concurrent WCR monitoring with Pherocon AM yellow sticky traps and aerial nets to capture flying insects, along with beetle dissections, analysis of soil samples, root injury ratings, and weather monitoring added other dimensions to the picture of WCR movement and abundance in different crops.

## Intrafield Movement: Western Corn Rootworm Beetles Really Get Around in Cornfields

Results from our 2001–2004 intrafield movement study are presented in Table 1. WCR movement rates within cornfields were measured under two different field settings. From 2001 to 2002, sampling occurred in a field containing 20 plots of nontransgenic corn and four plots of MON863 (the precommercialization name for YieldGard® Rootworm). Each row was 30 in. (0.76 m) in width, and each plot spanned eight rows. The maximum distance between a nontransgenic plot and a transgenic one was four plots (23.8 m). From 2003 to 2004, sampling was conducted in a 4-acre field divided into 31 corn plots; the nontransgenic isoline of the transgenic corn was grown in 29 of the plots, and a commercial transgenic corn variety was grown in another two plots (plots 8 and 24). YieldGard® Rootworm

was the transgenic variety in 2003; YieldGard® Corn Borer (expressing the Cry1Ab protein from *B. thuringiensis*) was used in 2004.

Beetles were regularly collected from every corn plot, promptly killed and frozen with dry ice, and returned to the laboratory where they were counted and sorted by sex before storage at −80°C. WCR were processed for detection of ingested transgenic corn tissue by placing one washed individual in a microcentrifuge tube of buffer and pulverizing it with 5–10 s burst of vibrational energy from a cell disruptor. A lateral flow test strip (ImmunoStrip; AgDia, Inc., Elkhart, IN or QuikStix, EnviroLogix, Portland, ME) was then inserted into each tube and allowed to stand for 5–10 minutes as liquid in the tubes was drawn up through the strip. In the presence of Cry3Bb1 protein, two red lines show up on the test strip, and an insect is scored as "positive for Cry3Bb1." The top line confirms that the test conditions were correct and the second line indicates that Cry3Bb1 protein was present in the sample. If no Cry3Bb1 protein was present, only the first line would show up

**Table 1.** Western corn rootworm (WCR) movement rates within cornfields and yearly abundance in cornfields between 2001-2004.

| | Year[1] | | | |
|---|---|---|---|---|
| **Measurement** | **2001[2]** | **2002** | **2003** | **2004** |
| Intra-cornfield movement rate (m/d) | 7.5 | 8.7 | 10.8/13.9[3] | tbd |
| WCR abundance in cornfields (WCR/min)[4] | 18.4 | 7.1 | 12.6 | 11.7 |

[1] 2001–2003 transgenic corn was YieldGard® Rootworm (expressing Cry3Bb1 protein), 2004 transgenic corn was YieldGard® Corn Borer (expressing Cry1Ab protein).

[2] 2001 sampling in corn for movement rate determination occurred on only 1 day: July 28th; n=960 WCR. In 2002-2004 sampling occurred on 8-12 dates; n=6,760 WCR (2002) and 9,683 WCR (2003).

[3] Greatest distance between YieldGard® Rootworm corn plots was increased from 4 plots to 8 plots (24.4 to 48.8 m); first rate is based on collections upto 4 plots from YieldGard® Rootworm, second rate is based on collections upto 8 plots from YieldGard® Rootworm.

[4] Data from period of peak abundance; last two weeks of July (2001-2004).

tbd: These insects have not yet been processed for detection of Cry1Ab.

The mean (2001–2003) rate of WCR intrafield movement for was ~9 m/day; over an entire season, the rate is similar for males and females. Early in the 2003 early season, when adult female emergence had not yet peaked and proportion of females in the population was low, male movement rates were ~30% higher than the 10.8 or 13.9 m/day season average. The male movement rate dropped once females became abundant. Elevated male movement rates when females are scarce may improve the mixing of refuge and transgenic field populations by causing males that emerge in transgenic corn to travel more widely. If those males encounter a refuge strip or block, the greater relative abundance of available females in those areas may hold them in the refuge where they would be unlikely to mate with potentially resistant females.

Exclusive of the 2001 sample (movement was monitored on only 1-day in 2001), WCR abundance in 2003 and 2004 was higher than in 2002, and the movement rates also were higher in 2003. If high beetle abundance increases overall movement rates, the flux of WCR dispersing out of refuges could be greater in years like 2003 and 2004. If observed, elevated intrafield movement rates in 2004 season samples would be supportive of a positive relationship between WCR abundance and movement rates in cornfields.

Long-distance movement or migration out of cornfields is not accounted for in these measurements. Tests on flying WCR captured from a 10-m platform immediately downwind of the 2003 test cornfield, revealed that the proportion of WCR testing positive for Cry3Bb1 protein was the same as the proportion of YieldGard® Rootworm corn plants in our field (6%). This suggests that WCR flight at 10 m is of local origin. Detection of ingested transgenic tissue in flying WCR could be used to track some WCR to greater heights and distances from our plots. If "marked" insects can be captured at greater elevation, these data would help measure the potential for long distance WCR movement and contribute to developing a mitigation plan to manage and contain a population of Bt-resistant WCR, should one arise.

## Interfield Movement: All Crops are Not Treated Equally by Western Corn Rootworm Beetles

Results from our 2003–2004 of interfield movement study are presented in Table 2. A goal of this study was to evaluate WCR responses to an alternative rotated crop, wheat, and an alternative cropping pattern, double-cropped wheat–soybean. Preliminary data suggested that wheat (actually wheat stubble; wheat was harvested in both years before significant interfield WCR movement began) would present a hot–dry environment that would be less acceptable to egg-laying females than soybean. Double-cropping wheat with soybean (soybean was planted the into the wheat stubble the day of wheat harvest) created a situation where inhospitable wheat stubble conditions

gradually became like a more soybean field over the season. The intermediate character of the double-cropped wheat and soybean fields is evident in several of the field measurements in Table 2.

Greater abundance of WCR within the soybean canopy (in sweep samples) and flying just above the canopy (reflected in Pherocon AM sticky trap and flying insect captures) shows that WCR were most active around soybean fields in both years. The differences between soybean and the other crops are all the more remarkable because each of six, 0.8-acre soybean plots was immediately adjacent to a 0.8-acre plot of wheat or double-cropped wheat–soybean on either side of the central corn strip.

Upon leaving a YieldGard® Rootworm corn strip, WCR distributed themselves differently in the three crops. Although WCR abundance differed by at least an order of magnitude in both years, in 2003, there were no differences in WCR abundance in soybean or double-cropped wheat–soybean at increasing distance from the YieldGard® Rootworm corn strip. In wheat, there were peaks of abundance in the first row adjacent to corn and at 16 rows from corn. In 2004, there were no differences in WCR abundance in soybean or wheat at increasing distance; however, in double-cropped wheat–soybean, WCR were significantly more abundant in the first two rows next to corn than at 32 rows from corn.

In general, the proportion of insects that test positive for the presence of ingested Cry3Bb1 protein declines with increasing distance from the adjacent strip of YieldGard® Rootworm corn. Approximately 68% of WCR in row 1 of the soybean field were positive for Cry3Bb1 protein compared with 71 and 81% of WCR in row 1 of double-cropped wheat–soybean and wheat, respectively. At 32 rows from corn, 15, 28, and 41% were positive for Cry3Bb1 in soybean, double-cropped wheat–soybean, and wheat, respectively. The overall proportions of Cry3Bb1-positve WCR in soybean, double-cropped wheat–soybean, and wheat were 0.45, 0.44, and 0.64, respectively. The total number of WCR testing positive for Cry3Bb1 protein at all sampled rows was used to calculate a movement rate (meters per day) for each crop. Movement from corn to wheat and double-cropped wheat–soybean were greater than movement into soybean in 2003 and in the preliminary results from 2004. Regardless of crop, however, the calculated interfield movement rate is less than the intrafield movement rate (Table 1).

WCR can fly out of corn and travel far into the rotated crops. Occasionally, WCR obtained during flying insect collections (Table 2) were observed to leave corn and cover the distance between the corn and where they were collected in one flight (~16-20 rows away from the corn). None of these insects have been processed for transgenic tissue detection. Were they processed, we predict that a higher proportion

**Table 2.** Western corn rootworm (WCR) movement rates from corn into three rotated crops and beetle population measurements for WCR sampled in soybean, wheat, and double-cropped wheat-soybean during 2003 and 2004.

| | Year and Crop | | | | | |
|---|---|---|---|---|---|---|
| | 2003 | | | 2004 | | |
| **Measurement** | **Soybean** | **Wheat-Soybean** | **Wheat** | **Soybean** | **Wheat-Soybean** | **Wheat** |
| Inter-field movement rate (m/d)[1,2] | 4.8 b | 6.1 a | 6.5 a | 5.8 a | 7.8 a | 6.2 a |
| WCR sweep abundance (WCR/100 sweeps) | 46 a | 1.9 b | 1.2 b | 114 a | 13.9 b | 4.4 b |
| Flying WCR collection rate (WCR/min) | 1.4 a | 0.6 b | 0.3 b | 1.3 a | 0.8 b | 0.5 b |
| Pherocon AM sticky trap captures (WCR/trap/d)[3] | 10.8 a | 3.5 b | 3.7.b | 19.3 a | 5.9 b | 4.1 b |
| Root-rating during following year (1-6 scale) | 5.0 a | 3.1 b | 2.7 c | tbd | tbd | tbd |
| Eggs in soil (eggs per 500ml sample) | 1.3 a | 3.0 a | 1.2 a | tbd | tbd | tbd |

[1] 2003 movement rate calculations based on Cry3Bb1 detection in n=13,799 WCR from soybean, n=1,789 WCR from wheat-soybean, and n=376 WCR from wheat. 2004 movement data are preliminary; representing insects from 5 of 21 sample dates. 2004 movement calculations based on n=1,662 WCR from soybean, n=76 WCR from wheat-soybean, and n=41 WCR from wheat.

[2] Means bearing the same letter are not statistically different at a=0.05.

[3] Data from last week of July and 1st three weeks of August, 2003-2004; 6 traps per 0.8 acre field.

tbd: These measurements were unavailable at the time of submission.

of the flying WCR above wheat fields should test positive for Cry3Bb1. If we could have collected some of the insects that moved beyond our sampling endpoint at 32 rows from the YieldGard® Rootworm strip, our calculated movement rate would have been higher. As such, interfield movement rates calculations should be viewed as conservative.

Dissection of females ($n$ =570) collected during the first month of sweep sampling in soybean fields and not used to test for Cry3Bb1 reveals that age and reproductive development influence WCR movement. Based on the presence of a large spermatophore (a male-produced mating plug deposited in the female reproductive tract during copulation and retained for only a few days), newly mated females tended to be concentrated at eight rows and beyond. More mature females with mature eggs and no spermatophore were concentrated in rows 1, 2, 4, and 8; mean ovarian development was also highest in the soybean rows nearest to the cornfield. Typically, newly mated females disperse from the field where they emerged to locate another cornfield; these females comprise 84% of the population captured flying over corn and soybean fields at 10 m (Spencer et al. 2004). The newly mated females captured in soybean fields at eight rows from corn and beyond may be a subset of the young female population that did not ascend from cornfields to engage in long distance flights. If they express their "young female" tendency to disperse at a lower elevation, this may explain why they are concentrated at greater distances from corn. It is also possible that soybean herbivory has influenced patterns of beetle movement. Among dissected insects, the proportion containing soybean tissue in their gut contents increased with increasing distance from the YieldGard® Rootworm strip. Mabry and Spencer (2003) and Mabry et al. (2004) found that soybean feeding, which provides little or no nutritional benefit to WCR females, increased WCR activity and stimulated egg laying. If young females are more sensitive to the effects of poor nutrition than older, larger females with greater fat body reserves, they may be impelled to move more when they encounter soybean.

There were no differences in the number of eggs recovered from soil samples across the three rotated crops, although mean egg laying in the corn strips (4.6 eggs/sample) was significantly greater than that in wheat or soybean. Significant differences in root injury ratings for the same first-year corn hybrid planted in the former rotated corn plots indicates that larval pressure, and thus the starting egg populations differed by planting. For the relatively few samples we were able to collect from our plots (4 samples × 3 replicates per plot × 3 fields), the variation in egg counts (standard deviations were 2 to 4× the mean) made it difficult to draw any conclusions about egg laying based on egg abundance in the soil. A regression of 2003 sticky trap counts (WCR per trap per day) versus 2004 root injury for each plot was very strong ($y = 3.18x - 5.4$; $F = 102.6$; $df = 1,10$; $P < 0.0001$; $r^2 = 0.91$). As demonstrated by O'Neal et al. (2001), WCR captures on Pherocon AM sticky traps are an excellent indicator of future root injury.

The 2004 capture rate for WCR on sticky traps in soybean was many times the economic threshold (5 WCR/trap/day), capture rates for double-cropped wheat–soybean also exceeded the economic threshold. WCR captures on wheat field sticky traps were below the economic threshold. If 2004–2005 winter egg survival is good and favorable conditions prevail during egg hatch, there is a potential for a large 2005 WCR population with an expectation of significant root injury in unprotected first-year corn following soybean and double-cropped wheat–soybean.

## Conclusions

Detection of ingested transgenic corn tissue in moving insects was an efficient way to monitor intra- and interfield movement of WCR beetles. Intrafield movement rates of WCR beetles averaged 9 m/day in corn. This rate of intrafield movement is great enough to ensure that good mixing between nontransgenic refuges and transgenic crop areas. Greater intrafield male movement when females are scarce and greater overall movement when WCR populations are high may further enhance the effectiveness of refuges.

Interfield movement from corn into wheat or double-cropped wheat–soybean was faster than movement into soybean. Like intrafield movement, higher WCR populations may lead to greater movement rates. The distribution of WCR females in soybean rows at increasing distance from adjacent YieldGard® corn was not uniform with respect to female age and reproductive status. Unfavorable conditions (dry and hot) in wheat stubble may contribute to faster movement through wheat. All crops are not treated equally by western corn rootworm beetles, WCR were significantly more abundant in and around soybean plots as measured by several different means. High 2003 WCR abundance in soybean (as measured with Pherocon AM sticky traps) translated into very significant root injury in first-year corn following soybean during 2004.

Although they were next to the soybean plots, wheat and double-cropped wheat–soybean plots had significantly lower WCR abundance and escaped significant root injury in 2004. Our data suggest that rotated corn after wheat and double-cropped wheat–soybean could have been grown at our field site in 2004 without a need to apply soil insecticide to protect the corn roots. However, this may not work every year—the mean WCR capture on the 2004 Pherocon AM sticky traps in soybean and double-cropped wheat–soybean both exceeded the 5 WCR/trap/day economic

threshold. Under very high WCR populations, with favorable winter survival, egg-laying in less preferred crops may still exceed the economic threshold and lead to significant injury in rotated cornfields.

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## References

Coats, S.A., J.J. Tollefson, and J.A. Mutchmor. 1986. A study of migratory flight in the western corn rootworm (Coleoptera: Chrysomelidae). Environmental Entomology 15: 620–625.

Coats, S.A., J.A. Mutchmor, and J.J. Tollefson. 1987. Regulation of migratory flight by juvenile hormone mimic and inhibitor in the western corn rootworm (Coleoptera: Chrysomelidae). Annals of the Entomological Society of America 80: 697–708.

EPA Office of Pesticide Programs. 2003. Biopesticides registration action document: event MON863 Bacillus thuringiensis Cry3Bb1 corn. http://www.epa.gov/pesticides/biopesticides/ingredients/tech_docs/cry3bb1/.

Grant, R.H., and K.P. Seevers. 1989. Local and long-range movement of adult western corn rootworm (Coleoptera: Chrysomelidae) as evidenced by washup along southern Lake Michigan shores. Environmental Entomology 18: 266–272.

Grant, R.H., and K.P. Seevers. 1990. The vertical movement of adult western corn rootworms (*Diabrotica virgifera virgifera*) relative to the transport of momentum and heat. Agricultural and Forest Meteorology 49: 191–203.

Hagler, J.R., and C.G. Jackson. 2001. Methods for marking insects: current techniques and future prospects. Annual Review of Entomology 46: 511–543.

Isard, S.A., M.A. Nasser, J.L. Spencer, and E. Levine. 1999. The influence of weather on western corn rootworm flight activity at the borders of a soybean field in east central Illinois. Aerobiologia 15: 95–104.

Isard, S.A., J.L. Spencer, M.A. Nasser, and E. Levine. 2000. Aerial movement of western corn rootworm, *Diabrotica virgifera virgifera* (Coleoptera: Chrysomelidae): Diel periodicity of flight activity in soybean fields. Environmental Entomology 29: 226–234.

Lance, D.R., N.C. Elliott, and G.L. Hein. 1989. Flight activity of *Diabrotica* spp. at the borders of cornfields and its relation to ovarian stage in *D. barberi*. Entomologia Experimentalis et Applicata 50: 60–67.

Levine, E., J.L. Spencer, S.A. Isard, D.W. Onstad, and M.E. Gray. 2002. Adaptation of the western corn rootworm, *Diabrotica virgifera virgifera* LeConte (Coleoptera: Chrysomelidae) to crop rotation: evolution of a new strain in response to a cultural management practice. American Entomologist 48: 94–107.

Mabry, T.R. and J.L. Spencer. 2003. Survival and Oviposition of a Western Corn Rootworm Variant Feeding on Soybean. Entomologia Experimentalis et Applicata 109: 113–121.

Mabry, T.R., J.L. Spencer, E. Levine, and S.A. Isard. 2004. Western corn rootworm (Coleoptera: Chrysomelidae) behavior is affected by alternating diets of corn and soybean. Environmental Entomology 33: 860–871.

Metcalf, R.L. 1983. Implications and prognosis of resistance to insecticides, in Pest Resistance to Pesticides (G.P. Georghiou and T. Saito. eds) pp 703–733. Plenum Press, New York.

Naranjo, S.E. 1990a. Comparative flight behavior of *Diabrotica virgifera virgifera* and *Diabrotica barberi* in the laboratory. Entomologia Experimentalis et Applicata 55: 79–90.

Naranjo, S.E. 1990b. Influence of two mass-marking techniques on survival and flight behavior of *Diabrotica virgifera virgifera* (Coleoptera: Chrysomelidae). Journal of Economic Entomology 83: 1360–1364.

Naranjo, S.E. 1991. Movement of corn rootworm beetles, *Diabrotica* spp. (Coleoptera: Chrysomelidae), at cornfield boundaries in relation to sex, reproductive status, and crop phenology. Environmental Entomology 20: 230–240.

O'Neal, M.E., M.E. Gray, S. Ratcliffe, and K.L. Steffey. 2001. Predicting western corn rootworm larval injury to rotated corn with Pherocon AM traps in soybeans. Journal of Economic Entomology 94: 98–105.

National Corn Growers Association. 2001. Insect resistance management fact sheet for *Bt* corn. http://www.ncga.com/.

Onstad, D.W., C.A. Guse, J.L. Spencer, E. Levine, and M.E. Gray. 2001. Modeling the dynamics of adaptation to transgenic corn by western corn rootworm (Coleoptera: Chrysomelidae). Journal of Economic Entomology 94: 529–540.

Spencer, J.L., S.A. Isard, and E. Levine. 1999. Free flight of western corn rootworm (*Diabrotica virgifera virgifera* LeConte) to corn and soybean plants in a walk-in wind tunnel. Journal of Economic Entomology 92: 146–155.

Spencer, J.L., T.R. Mabry, and T. Vaughn. 2003. Use of transgenic plants to measure insect herbivore movement. Journal of Economic Entomology 96: 1738–1749.

Spencer, J.L., T.R. Mabry, E. Levine, and S.A. Isard. 2004. Movement, dispersal, and behavior of western corn rootworm adults in rotated corn and soybean fields, in Western Corn Roo-

tworm: Ecology and Management (S. Vidal, U. Kuhlmann, and C.R. Edwards eds). CAB Publishing (in press).

USDA National Agricultural Statistics Survey, Agricultural Statistics Board. 2004. Agricultural chemical usage: 2003 field crops summary. May 2004.

Van Woerkom, G.J., F.T., Turpin, and J.R. Barrett, Jr. 1980. Influence of constant and changing temperatures on locomotory activity of adult western corn rootworms (*Diabrotica virgifera*) in the laboratory. Environmental Entomology 9: 32–34.

Van Woerkom, G.J., F.T., Turpin, and J.R. Barrett, Jr. 1983. Wind effect on western corn rootworm (Coleoptera: Chrysomelidae) flight behavior. Environmental Entomology 12: 196–200.

# Insecticidal Seed Treatments and Soil Insecticides for Corn Rootworm Control

*Kevin Steffey, Mike Gray, and Ron Estes*

Entomologists at the University of Illinois have conducted trials to evaluate the efficacy of corn rootworm control products for many years. During the past 20 years, we have established these standard efficacy trials annually at three University of Illinois research centers—DeKalb, Monmouth, and Urbana. We plant our corn rootworm control trials into areas in which a trap crop (late-planted, mixed maturity corn hybrids + pumpkins) was planted the previous year. The trap crop attracts egg-laying female rootworms. Typically, rootworm larval feeding damage is significant in the untreated check plots every year, enabling us to compare and contrast the consistency of performance of corn rootworm control products over time. Although the amount of corn rootworm larval damage in most commercial cornfields usually is not as great as the amount of corn rootworm larval damage that we observe in our trials, the results from our trials enable corn producers to ascertain the performance of corn rootworm control products under worst-case conditions.

## Plot Information and Methods

### *Plot Establishment*

In 2004, we planted all of our corn rootworm control trials in mid- to late April (Urbana,19 April; Monmouth, 27 April; and DeKalb, 28 April). Two corn hybrids were planted in each of these trials, Golden Harvest H-8588RW (a YieldGard Rootworm [YGRW] hybrid) and Golden Harvest H-8799 (the nontransgenic isoline of H-85588RW). Each treatment plot was four rows in width and 35 ft (DeKalb) or 40 ft (Monmouth and Urbana) in length. The experimental design was a randomized complete block with four replications.

All granular insecticides were applied through either Noble® units or modified SmartBox® units mounted on each row of the four-row planter. These units were calibrated to apply the designated amount of each product per 1,000 row ft. Granules were applied either in a 6-inch band over the row or in the seed furrow, according to protocol. Spring tines mounted behind the firming wheels incorporated the granules into the soil.

Capture 2EC and Lorsban 4E were applied in 6-inch bands over the rows with application equipment calibrated to deliver 5 gallons per acre (gpa) at 47 pounds per square inch (psi). Spring tines mounted behind the firming wheels incorporated the liquid insecticides into the soil.

Seeds of the selected corn hybrid were sent to Syngenta and Gustafson personnel for treatment with Cruiser and Poncho 1250, respectively. Before planting any of the plots, the designated numbers of treated seeds (based upon a population of 30,000 plants per acre) were counted and placed in individual envelopes, which were emptied into modified seed hoppers and planted in the appropriate locations within each plot.

Seeds of the YGRW hybrid (Golden Harvest H-8588RW) were treated with Poncho 250. Before planting any of the plots, the designated numbers of YGRW seeds (based upon a population of 30,000 plants per acre) were counted and placed in individual envelopes, which were emptied into modified seed hoppers and planted in the appropriate locations within each plot.

### *Plot Evaluations and Measurements*

All evaluations were conducted in each treatment plot within each replication at each location. All data were analyzed with Agricultural Research Manager (Gylling Data Management). However, the results from all of the evaluations are not presented in this article.

Plant populations were estimated in 1/1,000 acre in each of two rows in each plot. There were no significant differences among plant populations within a given location (the data are not presented).

Rootworm damage evaluations were conducted in mid-July. Five roots were dug from the center two rows in each plot in each replication, for a total of 20 roots per treatment (five roots per treatment × four replications). All roots were

returned to the Agricultural Engineering Farm in Urbana to be washed and rated. The roots were soaked in tanks of water and then cleaned with power washers to expose the rootworm larval feeding damage. Each root was rated on a scale of 1 to 6 (Hills and Peters 1971), and individual root ratings were recorded. The root-rating scale follows:

1. No damage or only a few minor feeding scars
2. Feeding scars evident, but no roots eaten off to within 1½ inches of the plant
3. Several roots eaten off to within 1½ inches of the plant, but never the equivalent of an entire node of roots destroyed
4. One node of roots completely destroyed
5. Two nodes of roots completely destroyed
6. Three or more nodes of roots destroyed

Percentage of lodging was estimated at each location in August and in September. All estimates of lodging were taken from 1/1,000 acre in one row of each plot. Lodging was defined as a plant leaning 45° or more from vertical. Some of the lodging information from the estimates in August was presented in an article in *The Bulletin* (Gray and Steffey 2004). Lodging was estimated again on 28 September (Urbana and Monmouth) and 29 September (DeKalb). Although percentage lodging averages are presented in Tables 1–3, at the time this article was written, the lodging data had not been statistically analyzed.

**Table 1.** Results from corn rootworm control trial, Urbana, Illinois, 2004.

| Product | Rate of application[1,2] | Placement | Mean root rating[3,4,5] | Ave. percentage lodging[6] |
|---|---|---|---|---|
| Force 3G | 4 oz | Band | 2.45f | 0 |
| Lorsban 15G | 8 oz | Band | 2.65ef | 0 |
| Lorsban 4E | 2.4 oz | Band | 2.65ef | 4 |
| Nufos 15G | 8 oz | Band | 2.65ef | 0 |
| Aztec 2.1G | 6.7 oz | Band | 2.90def | 6 |
| Fortress 5G[7] | 4.5 oz | Furrow | 2.90def | 0 |
| Fortress 2.5G | 7.4 oz | Furrow | 2.95def | 8 |
| Aztec 4.67G[7] | 3.0 oz | Furrow | 3.01def | 0 |
| YGRW[8] | — | — | 3.15def | 66 |
| Force 3G[7] | 3.0 oz | Band | 3.20def | 5 |
| Fortress 5G[7] | 3.7 oz | Furrow | 3.20def | 6 |
| Aztec 4.67G[7] | 3.0 oz | Band | 3.40cde | 0 |
| Capture 2EC | 0.37 oz | Band | 3.55cd | 32 |
| Poncho 1250 | 1.25 mg | On seed | 4.05bc | 16 |
| Cruiser | 1.25 mg | On seed | 4.15bc | 51 |
| Empower 2 | 8.0 oz | Furrow | 4.53b | 58 |
| Empower 2 | 8.0 oz | Band | 4.70b | 54 |
| Untreated check | — | — | 5.80a | 100 |

[1] Rates of application for band and furrow placements are ounces (oz) of product per 1,000 ft of row.

[2] Rates of application for seed treatments are milligrams (mg) of active ingredient (AI) per seed.

[3] Root ratings are based upon the 1-to-6 root-rating scale developed by Hills and Peters (1971).

[4] Average root ratings are based upon root ratings of five individual roots per treatment in each of four replications.

[5] Means followed by the same letter do not differ significantly ($P = 0.05$, Duncan's new multiple range test).

[6] Percentage lodging was estimated in 1/1,000 acre in one row of each treatment in each of four replications. Lodging was defined as a plant leaning 45° or more from vertical. Average lodging is presented as rounded, whole numbers.

[7] Applied with modified SmartBox metering units.

[8] YieldGard Rootworm corn hybrid was Golden Harvest H-8588RW. All other treatments were applied to Golden Harvest H-8799 (the nontransgenic isoline of H-85588RW).

In October, all treatments in all three trials were harvested and weighed individually with a small-plot combine. At Urbana and DeKalb, two rows per treatment were harvested; at Monmouth, one row per treatment was harvested. At the time this article was written, the yield data had not been compiled and analyzed. Yield data will be presented during the conference.

Monthly rainfall amounts at each location (Table 4) were determined from data generated by the Illinois State Water Survey.

**Table 2.** Results from corn rootworm control trial, DeKalb, Illinois, 2004.

| Product | Rate of application[1,2] | Placement | Mean root rating[3,4,5] | Ave. percentage lodging[6] |
|---|---|---|---|---|
| YGRW[7] | — | — | 2.35e | 56 |
| Force 3G | 4.0 oz | Band | 2.65de | 4 |
| Aztec 2.1G | 6.7 oz | Band | 2.75cde | 20 |
| Fortress 2.5G | 7.4 oz | Furrow | 2.75cde | 0 |
| Aztec 4.67G[8] | 3.0 oz | Band | 2.95cd | 33 |
| Fortress 5G[8] | 3.7 oz | Furrow | 2.95cd | 29 |
| Aztec 4.67G[8] | 3.0 oz | Furrow | 3.05cd | 46 |
| Force 3G[8] | 3.0 oz | Band | 3.15cd | 31 |
| Lorsban 4E | 2.4 oz | Band | 3.15cd | 23 |
| Nufos 15G | 8.0 oz | Band | 3.18cd | 11 |
| Lorsban 15G | 8.0 oz | Band | 3.30c | 4 |
| Capture 2EC | 0.37 oz | Band | 3.90b | 73 |
| Poncho 1250 | 1.25 mg | On seed | 3.95b | 83 |
| Empower 2 | 8.0 oz | Furrow | 4.13b | 93 |
| Empower 2 | 8.0 oz | Band | 4.70a | 100 |
| Untreated check | — | — | 5.00a | 96 |
| Cruiser | 1.25 mg | On seed | 5.05a | 100 |

[1] Rates of application for band and furrow placements are ounces (oz) of product per 1,000 ft of row.

[2] Rates of application for seed treatments are milligrams (mg) of active ingredient (AI) per seed.

[3] Root ratings are based upon the 1-to-6 root-rating scale developed by Hills and Peters (1971).

[4] Average root ratings are based upon root ratings of five individual roots per treatment in each of four replications.

[5] Means followed by the same letter do not differ significantly ($P = 0.05$, Duncan's new multiple range test).

[6] Percentage lodging was estimated in 1/1,000 acre in one row of each treatment in each of four replications. Lodging was defined as a plant leaning 45° or more from vertical. Average lodging is presented as rounded, whole numbers.

[7] YieldGard Rootworm corn hybrid was Golden Harvest H-8588RW. All other treatments were applied to Golden Harvest H-8799 (the nontransgenic isoline of H-85588RW).

[8] Applied with modified SmartBox metering units.

## Results

### *Urbana*

Table 1 shows the mean root rating and average percentage lodging for each treatment in our trial at Urbana. The mean root rating in the untreated check plots was 5.80 (almost three nodes of roots destroyed), indicating that rootworm larval feeding damage was severe. Although the mean root ratings for all treatments were significantly lower than the mean root rating for the untreated check, severe rootworm feeding damage was observed in several treatments.

Based upon statistical analysis, the mean root ratings for the first 11 treatments listed in Table 1 were not significantly different (mean root ratings ranging from 2.45 to 3.2). The mean root rating for Force 3G (4-oz rate, applied in a band) was significantly lower than the mean root ratings for Aztec 4.67G (3-oz rate , applied in a band), Capture 2EC, Poncho 1250, Cruiser, and both placements of Empower 2. The mean root ratings for Empower 2 were significantly higher than the mean root ratings for all other products except Poncho 1250 and Cruiser. The mean root ratings for Poncho 1250 and Cruiser were significantly higher than the mean root ratings for all other products except Aztec 4.67G (3-oz rate, applied in a band), Capture 2EC, and Empower 2.

The mean root rating for YGRW corn at Urbana was 3.15, not significantly different from the mean root rating (2.45) of Force 3G (4-oz rate, applied in a band). However, based upon past experiences with YGRW corn, the mean root rating of 3.15 for YGRW corn was greater than expected. In the past, mean root ratings for YGRW corn were always lower than 3.0 in University of Illinois trials. A discussion about the greater-than-expected damage to YGRW corn is provided in another article in these proceedings (Transgenic YieldGard Rootworm Hybrid Stumbles in Urbana Experiment: Why? by M.E. Gray and K.L. Steffey).

All sampled plants in the untreated check at Urbana were lodged. More than 50% lodging was estimated in the plots treated with Cruiser (51%), Empower 2 applied in both a band (54%) and in furrow (58%), and YGRW corn (66%). Lodging in the Capture-treated plots was 32%. In general,

the percentage lodging increased when the mean root rating was greater than 4.0

### *DeKalb*

Table 2 shows the mean root rating and average percentage lodging for each treatment in our trial at DeKalb. The mean root rating in the untreated check plots was 5.0 (two nodes of roots destroyed), indicating that rootworm larval feeding damage was severe. Although the mean root ratings for almost all treatments were significantly lower than the mean root rating for the untreated check, severe rootworm feeding damage was observed in several treatments.

The mean root ratings for the first four treatments listed in Table 3 were not significantly different (mean root ratings ranging from 2.35 to 2.75). The mean root rating for YGRW corn (2.35) was significantly lower than the mean root ratings for all treatments except Force 3G (4-oz rate, applied in a band), Aztec 2.1G, and Fortress 2.5G. The mean root ratings for Capture 2EC (3.9), Poncho 1250 (3.95), and Empower 2 (applied in furrow) were significantly greater than the mean root ratings for all treatments except Empower 2 (applied in a band) and Cruiser. The mean root ratings for Cruiser and Empower 2 (applied in a band) were not significantly different from the mean root rating for the untreated check.

Strong winds caused significant lodging in several treatments at DeKalb. Almost all plants (96%) in the untreated check plot lodged. Lodging exceeded 50% in the following treatment plots: YGRW corn (56%), Capture 2EC (73%), Poncho 1250 (83%), Empower 2 applied in furrow (93%), Empower 2 applied in a band (100%), and Cruiser (100%). Single-digit percentage of lodging occurred in only three treatment plots: Force 3G (4 oz rate, applied in a band; 4%), Fortress 2.5G (0%), and Lorsban 15G (4%).

**Table 3.** Results from corn rootworm control trial, Monmouth, Illinois, 2004.

| Product | Rate of application[1,2] | Mean Placement | Ave. percentage root rating[3,4,5] | lodging[6] |
|---|---|---|---|---|
| YGRW[7] | — | — | 1.80g | 10 |
| Fortress 2.5G | 7.4 oz | Furrow | 2.55f | 1 |
| Fortress 5G[8] | 3.7 oz | Furrow | 2.55f | 13 |
| Nufos 15G | 8.0 oz | Band | 2.65ef | 2 |
| Aztec 4.67G[8] | 3.0 oz | Band | 2.80def | 2 |
| Force 3G[8] | 3.7 oz | Band | 2.85def | 3 |
| Lorsban 15G | 8.0 oz | Band | 2.95def | 0 |
| Lorsban 4E | 2.4 oz | Band | 3.00def | 5 |
| Aztec 4.67G[8] | 3.0 oz | Furrow | 3.15def | 0 |
| Aztec 2.1G | 6.7 oz | Band | 3.25def | 6 |
| Force 3G | 4.0 oz | Band | 3.35de | 0 |
| Capture 2EC | 0.37 | Band | 3.45d | 1 |
| Poncho 1250 | 1.25 mg | On seed | 4.10c | 56 |
| Cruiser | 1.25 mg | On seed | 5.10b | 65 |
| Untreated check | — | — | 5.75a | 100 |

[1] Rates of application for band and furrow placements are ounces (oz) of product per 1,000 ft of row.

[2] Rates of application for seed treatments are milligrams (mg) of active ingredient (AI) per seed.

[3] Root ratings are based upon the 1-to-6 root-rating scale developed by Hills and Peters (1971).

[4] Average root ratings are based upon root ratings of five individual roots per treatment in each of four replications.

[5] Means followed by the same letter do not differ significantly ($P = 0.05$, Duncan's new multiple range test).

[6] Percentage lodging was estimated in 1/1,000 acre in one row of each treatment in each of four replications. Lodging was defined as a plant leaning 45° or more from vertical. Average lodging is presented as rounded, whole numbers.

[7] YieldGard Rootworm corn hybrid was Golden Harvest H-8588RW. All other treatments were applied to Golden Harvest H-8799 (the nontransgenic isoline of H-85588RW).

[8] Applied with modified SmartBox metering units.

### *Monmouth*

Table 3 shows the mean root rating and average percentage of lodging for each treatment in our trial at Monmouth. The mean root rating in the untreated check plots was 5.75 (almost three nodes of roots destroyed), indicating that rootworm larval feeding damage was severe. Although the mean root ratings for all treatments were significantly lower than the mean root rating for the untreated check, severe rootworm feeding damage was observed in several treatments.

The mean root rating for YGRW corn (1.8) was significantly lower than the mean root ratings for all other treat-

ments. The mean root ratings for the next nine treatments listed in Table 4 were not significantly different (mean root ratings ranging from 2.55 to 3.25). The mean root ratings for Fortress 2.5G and 5G (both 2.55) were significantly lower than the mean root ratings for Force 3G (4 oz rate, applied in a band; 3.35), Capture 2EC (3.45), Poncho 1250 (4.1), and Cruiser (5.1). The mean root rating for Nufos 15G (2.65) was significantly lower than the mean root ratings for Capture 2EC, Poncho 1250, and Cruiser. The mean root ratings for Poncho 1250 and Cruiser were significantly higher than the mean root ratings for all other treatments; however, the mean root rating for Poncho 1250 was significantly lower than the mean root rating for Cruiser.

Lodging was less evident at Monmouth than at either Urbana or DeKalb. However, all plants lodged in the untreated check plots, and lodging exceeded 50% in the Poncho 1250 plots (56%) and the Cruiser plots (65%). Double-digit percentage of lodging occurred in the YGRW corn plots (10%) and the Fortress 5G plots (13%).

## Discussion

The severe rootworm larval damage that occurred at all three of our trial locations in 2004 provided excellent circumstances for comparisons of efficacy of several corn rootworm control products. Differences in performance of some products among the three locations also serve as a reminder than soil and environmental conditions significantly influence the efficacy of corn rootworm control products. The performance of several rootworm control products varied by location and by formulation.

The economic index used by many entomologists is a root rating of 3.0 (several roots eaten off to within 1½ inches of the plant, but never the equivalent to an entire node). Rootworm damage resulting in a root rating above this index could lead to potential yield loss and be deemed unacceptable. As indicated previously, in general, as the mean root rating increased, the percentage of lodging increased. Severe lodging can contribute to yield loss. Only Fortress 2.5G applied in furrow held the mean root rating below 3.0 at all three locations, and lodging percentages in plots treated with Fortress 2.5G were 8, 0, and 1% at Urbana, DeKalb, and Monmouth, respectively. The mean root ratings for seven products were below 3.0 at two of the three locations: Aztec 2.1G (6.7-oz rate , applied in a band), Aztec 4.67G (3-oz rate, applied through a SmartBox in a band), Force 3G (4 oz rate, applied in a band), Fortress 5G (3.7 oz rate, applied in furrow), Lorsban 15G (8 oz rate, applied in a band), Nufos 15G (8 oz rate, applied in a band), and YGRW corn.

Empower 2 did not perform well under the intense pressure at Urbana and DeKalb (Empower 2 was not applied in the trial at Monmouth), with mean root ratings greater than 4.0 at both locations. Likewise, the seed treatments did not perform well at any of the three locations. The Cruiser and Poncho 1250 treatments had average root ratings ranging from 4.15 to 5.10 and 3.95 to 4.10, respectively. Regarding the performance of liquid insecticides, Lorsban 4E provided significantly better root protection than Capture 2EC at both Urbana and DeKalb.

**Table 4.** Monthly rainfall amounts (inches) at Urbana, DeKalb, and Monmouth, Illinois, 2004.

| Location | May | June | July | August |
|---|---|---|---|---|
| Urbana | 4.4 | 3.8 | 5.7 | 3.6 |
| DeKalb | 9.5 | 3.1 | 2.1 | 3.3 |
| Monmouth | 4.0 | 2.4 | 5.7 | 5.8 |

In several ways, the results from our rootworm control trials in 2004 substantiated most of the generalities about rootworm control that we have stated in the past. In general, when accurately applied and incorporated, granular insecticides provide better protection against corn rootworm larvae than liquid insecticides and seed treatments. The exception to this statement is Empower 2, which does not seem to be a very effective rootworm control product. It is also worth noting that Lorsban 4E, under the conditions of our trials in 2004, performed relatively consistently (mean root ratings of 2.65, 3.15, and 2.65 at Urbana, DeKalb, and Monmouth, respectively).

The insecticidal seed treatments currently on the market do not protect corn roots from corn rootworm larval damage very well when infestations of corn rootworm larvae are heavy. We have stated this before, based upon the results from our trials during the past few years, and the results from our trials in 2004 validate the statement. Producers should consider using another rootworm control tactic in fields with a high risk of severe rootworm damage.

A caveat about our rootworm control trials is in order. Many corn producers ask, "Why did product X work in your trials, but it didn't work for me?" Our three rootworm control trials provide only three snapshots of product efficacy each year; however, rootworm control products are used on millions of corn acres in Illinois each year. Because many factors (e.g., environmental conditions, lack of incorporation) affect the efficacy of rootworm control products and because soil and environmental conditions can differ significantly from one location to another, the results from our trials will not reflect the results that might be obtained under different conditions. Therefore, the only way to assess the reliability (or lack thereof) of a corn rootworm control product is to assess the consistency of a product's performance over time and geography. Producers should review

efficacy data from several objective sources, including results from other land-grant universities and from independent consultants. Also, producers should consider asking other producers about their experiences with corn rootworm control products. Products that perform consistently well in universities' and consultants' trials and in other producers' fields are the products that will be reliable under most circumstances. That having been said, however, no corn rootworm control product is "bulletproof," and certain circumstances can challenge even the most consistent product. For example, past research (Steffey et al. 1985) has shown that inadequate incorporation can reduce the effectiveness of some granular products. Consequently, we emphasize that all corn rootworm control products should be applied or planted with rigorous attention to label directions (e.g., placement, incorporation) to ensure that the product has the optimum likelihood for providing an acceptable level of root protection.

## References


Gray, M., and K. Steffey. 2004. Transgenic corn rootworm hybrid stumbles in Urbana experiment; some producers also report severe lodging with YieldGard Rootworm hybrids in commercial fields. *The Bulletin*, issue No. 22, September 2. University of Illinois Extension, Urbana-Champaign. http://www.ipm.uiuc.edu/bulletin/article.php?issueNumber=22&issueYear=2004&articleNumber=1.

Hills, T.M. and D.C. Peters. 1971. A method of evaluating postplant insecticide treatments for control of western corn rootworm larvae. Journal of Economic Entomology 64: 764–765.

Steffey, K., D. Kuhlman, and E. Levine. 1985. Corn rootworm control data—1985, pp. 37–49, in Thirty-eighth Illinois Custom Spray Operators Training Manual. Cooperative Extension Service, University of Illinois at Urbana-Champaign.

# Transgenic YieldGard Rootworm Hybrid Stumbles in Urbana Experiment: Why?

*Michael E. Gray and Kevin L. Steffey*

In 2004, producers across the Corn Belt finished their second growing season in which transgenic insecticidal cultivars (MON 863, Cry3Bb1, Vector ZMIR 13L) were available commercially to prevent corn rootworm larval damage. As with any new technology, we have much to learn about this new management approach for corn rootworms. Indeed, this past growing season yielded surprises with some YieldGard Rootworm hybrids in our experiments (Urbana and DeKalb), an experiment led by Purdue University entomologists (September 3, 2004 Newsletter, Issue No. 24, http://www.entm.purdue.edu/Entomology/ext/targets/p&c/index2004.htm), and in some producers' fields in Illinois. Since western corn rootworms were first found in Illinois (Rock Island County) in 1964 (Gray and Luckmann 1994), farmers have relied primarily upon crop rotation and soil insecticides to limit losses caused by corn rootworm larvae. Many soil insecticides registered for corn rootworms have come and gone during the past four decades. In fact, the U.S. Environmental Protection Agency (EPA) has registered (as of April 2003) 36 insecticide products for the control of corn rootworms (U.S. EPA 2003). Even the durable cultural management tactic of crop rotation eventually succumbed to the evolution of a variant of the western corn rootworm in Illinois (Levine et al. 2002). In the western Corn Belt, entomologists in Kansas and Nebraska have reported the development of resistance to methyl parathion and carbaryl due to the extensive use of these insecticides in adult control programs in both states for decades (Meinke et al. 1998, Sharf et al. 1999, Zhu et al. 2001, Parimi et al. 2003). The western corn rootworm is an impressive foe, and it seems prudent to continue the search for new strategies to manage this insect pest, particularly because we have a tendency to overuse and "break" pest management tactics that work well, at least initially. The potential benefits of transgenic insecticidal hybrids (MON 863) for producers are impressive.

A Scientific Advisory Panel (U.S. EPA 2002a) met in Arlington, VA, during August 27–29 2002 to offer advice and counsel to the U.S. EPA as part of the registration process as outlined by the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and described several important benefits to producers who choose to use YieldGard Rootworm hybrids: 1) "equivalent to or better than soil insecticides in terms of plant damage; 2) reduced applicator, handler, and farmer worker exposure to insecticides; 3) a narrow spectrum of activity could possibly eliminate or greatly reduce the environmental concerns generated by broader spectrum insecticides; 4) the technology is easy to use and does not delay planting; 5) the technology does not require special application equipment, the need for calibration, or the disposal/return of containers; and 6) performance consistency is improved since each plant is protected and this protection is relatively unaffected by weather." Rice (2003) further outlined many impressive potential benefits for transgenic corn rootworm hybrids: "increased economic benefits to farmers ($231 million from yield gains [$25–75/acre relative to no insecticide control, $4–12/acre relative to control with a soil insecticide] and $58 million in reduced insecticide risks and time savings)." In spite of these economic pluses, some concerns persist with this new technology, especially the potential development of resistance.

The Scientific Advisory Panel (U.S. EPA 2002a) was divided regarding the most appropriate resistance management plan to recommend to the U.S. EPA for implementation by American producers. Some panel members urged the EPA to recommend a 50% refuge; other members believed that a 20% refuge was more reasonable and would accomplish the goal of prolonging the usefulness of this technology. The North Central Region Technical Research Committee on Corn Rootworms and Soil Insects (NCR-46) recommended (May 29, 2001) that a 20% refuge should be used during the interim registration period (3 years). As indicated at the outset of this report, the transgenic management approach for corn rootworms is so new that the NCR-46 Committee outlined many knowledge gaps that need to be filled to construct an effective resistance management plan.

- "Characterize tissue expression, dose, and the mechanism by which corn rootworms survive on transgenic corn expressing Cry3Bb.
- Continue to quantify movement patterns of corn rootworm larvae when feeding on transgenic (expressing Cry3Bb) and nontransgenic corn.
- Quantify pre- and postmating dispersal of corn rootworm, movement within and between fields, and its implications for insect resistance management (IRM).
- Quantify the relative fitness of rootworm individuals that survive on transgenic corn versus nontransgenic corn.
- Reevaluate the host status of major grassy cornfield weeds and other grasses commonly found near corn; estimate the potential impact these alternate hosts may have on corn rootworm population dynamics.
- Continue to develop toxicological bioassays and resistance monitoring techniques.
- Determine the genetic nature of resistance to corn rootworm-active Cry compounds.
- Improve rearing techniques for certain corn rootworm species to facilitate e.g., laboratory and greenhouse bioassays, genetic studies.
- Generate more complete data sets on e.g., transgenic efficacy, adult emergence from transgenic corn. for all targeted corn rootworm species.
- Evaluate IRM options other than a refuge strategy, especially if an event is not classified as high dose.
- Examine the impacts of refuge configuration, including seed mixtures, on development of resistance and likelihood of farmer adoption.
- Continue to develop and refine computer simulation models that build on current knowledge to guide development of IRM strategies.
- Reconcile corn rootworm and European corn borer IRM needs into an optimal IRM plan."

The scientific experts on the NCR-46 Committee recognized we have much to learn about managing corn rootworms with transgenic insecticidal hybrids and prolonging the usefulness of this technology. Monsanto has provided funding to many researchers within the land-grant system to help address many of these data gaps and facilitated the exchange of information among scientists at conferences and other meetings.

In the first issue (March 20) of the 2003 *Pest Management and Crop Development Bulletin*, http://www.ipm.uiuc.edu/bulletin/pastpest/articles/200301b.html, we alerted producers who intended to plant YieldGard Rootworm hybrids that they should anticipate finding adult corn rootworms in their YieldGard Rootworm cornfields. These adults included immigrants as well as those emerging directly from YieldGard Rootworm fields. Unlike Bt hybrids (MON 810, high-dose event) deployed against European corn borers (in which survivorship of corn borer larvae is rare), the use of transgenic hybrids (MON 863, Cry3Bb1) for corn rootworm larvae results in plentiful adult emergence. Why? The MON 863 event is a non-high-dose product. In fact, the Scientific Advisory Panel that met to discuss this technology made the following observation: "... the use of SS (homozygous susceptible) survival rates was sufficient to demonstrate that MON 863 is not high dose, because SS survival is so much higher than that expected at 25× the LC99 (lethal concentration to 99% of a population)." An experiment at the University of Illinois confirmed that plentiful western corn rootworm survival occurs with the YieldGard Rootworm technology. In 2001, we placed adult emergence cages over transgenic corn plants (MON 863, Cry3Bb1, PN34G81) that were planted on 10 May. The cages were checked every 2 days for adult emergence. In total, 96 emergence cages were used in this replicated split-plot experiment. Based upon the number of adults emerging into these cages, we projected that 2,450 male western corn rootworm adults would emerge per acre from the MON 863 event corn. The number of females emerging per acre from the transgenic corn was 25,320. Overall, we projected that 27,770 adults would have emerged from 1 acre of transgenic corn (MON 863, Cry3Bb1); 91% of these were females. Emergence of males and females also was delayed from the transgenic corn rootworm hybrid compared with the nontransgenic isoline. Delayed emergence and survivorship data such as these have been reported by other entomologists from land-grant institutions. Skewed survivorship of males and females and delayed emergence patterns may lead to nonrandom mating and increase the speed at which resistance development could occur. Although MON 863 is a non-high-dose event, root protection afforded by this technology in university research plots across the Corn Belt had been exceptional.

In 2003, we established three corn rootworm product efficacy trials in trap-crop settings (late-planted corn interplanted with pumpkins) located near DeKalb, Monmouth, and Urbana. Root injury (1 to 6 scale) in our untreated check (DeKalb 60-15 hybrid) was 4.06 (one node destroyed), 5.75 (2¾ nodes destroyed), and 5.45 (2½ nodes destroyed), respectively. Planting dates for DeKalb, Monmouth, and Urbana were 28 May, 16 May, and 13 May, respectively. In 2003, corn rootworm larvae began hatching by 29 May across much of central Illinois. Despite the intensity of larval feeding, the DeKalb YieldGard rootworm hybrid offered excellent root protection at each experimental site:

DeKalb (root rating 1.45), Monmouth (2.05), and Urbana (1.35).

In 2004, we again established corn rootworm product efficacy plots in our three standard experiments in trap crop settings. Planting dates for DeKalb, Monmouth, and Urbana were 28 April, 27 April, and 19 April. These planting dates are considerably earlier compared with the previous year by 1 month, 19 days, and 24 days, respectively. The corn rootworm larval hatch in central Illinois was estimated to be about 1 week to 10 days earlier than that in 2003. In 2004, we planted a Golden Harvest (H-8588 RW) YieldGard corn rootworm hybrid and its isoline (Golden Harvest H-8799). Root injury (1 to 6 scale) in the check was severe at each location and averaged 5.0 (2 nodes destroyed), 5.75 (2¾ nodes destroyed), and 5.8 (nearly 3 nodes destroyed) at DeKalb, Monmouth, and Urbana, respectively. Root evaluations were conducted for each of these locations on 21 July, 15 July, and 10 July, respectively. Root injury ratings for the Golden Harvest YieldGard corn rootworm hybrid for DeKalb, Monmouth, and Urbana were 2.35, 1.80, and 3.15 (pruning occurred, considerably less than 1 node). The level of root injury at the Urbana experiment was greater than anticipated. Plants from our DeKalb, Monmounth, and Urbana trials were checked (by Monsanto) for expression and the results were positive.

On 13 July, a severe storm swept across central, north central, and east central Illinois counties. High winds and torrential rains characterized this impressive storm. Within a few days, we began to receive telephone calls and email inquiries concerning severely lodged corn, including concerns from some producers who had planted YieldGard Rootworm hybrids. Field visits were conducted in some of these producers' fields. Sometimes, root injury was greater than expected. In other fields, the level of root pruning was minimal in the YieldGard Rootworm fields. Yet, the fields were severely lodged and harvestability was severely compromised. Not long after these observations from commercial cornfields became more common, Ron Estes (Insect and Insecticide Evaluation Program Manager, Department of Crop Sciences, University of Illinois) noted that the YieldGard rootworm treatment (Golden Harvest H-8588RW) in our Urbana experiment had severe lodging. At this point, we elected to take more root injury and lodging evaluations from this treatment at all three of our experiments.

During the first week of August, we rated (1 to 6 scale) 40 roots (10 per replicate) for injury from the YieldGard rootworm treatment at the Urbana experiment. Slightly more than 3 weeks had elapsed since our original ratings were taken on 10 July. Root rating (1 to 6 scale) averages per replicate were 3.6, 3.4, 3.6, and 3.8 (overall average 3.6). The range in root injury was 3 to 4 (60% of the roots were rated 4.0). Not a single root rating of 1 or 2 was observed during the root evaluations in August. To more precisely quantify the level of pruning on these roots, we also rated them on the 0 to 3 rating scale. Root injury ratings per replicate were 1.43 (nearly 1½ nodes destroyed), 1.08 (1 node destroyed), 1.64 (slightly more than 1½ nodes destroyed), and 1.24 (slightly more than 1 node destroyed). The overall root rating (0 to 3 scale) was 1.35 (1 ⅓ node destroyed). This level of injury was much greater than we observed in July. In addition to the root evaluations, we measured the level of lodging that occurred in the YieldGard rootworm treatment. The percentage of plants lodged in each of the replicates (four-row plots) was 40, 79, 61, and 39%. By 28 September, the overall percentage of plants that had lodged in the YieldGard rootworm treatment was 66%.

Because of our experience with the YieldGard rootworm treatment at Urbana, we also took additional root ratings (12 August) and lodging counts at our DeKalb and Monmouth experiments. Root injury ratings (1 to 6 scale) for DeKalb by replicate were 2.6, 2.3, 2.3, and 2.2 (overall average 2.35). However, the range in root injury ratings for DeKalb was 2 to 5. As of 12 August, none of the plants in the YieldGard rootworm treatment were lodged in the DeKalb study. However, by 29 September, 56% of the plants in the YieldGard rootworm treatment had lodged. Root injury ratings (1 to 6 scale) in Monmouth for each replicate were 2.5, 2, 2.7, and 2.2 (overall average 2.35). The range in root injury was 2 to 4. The percentage of plants lodged in each replicate (four-row plots) was 29, 3, 9, and 0%.

Currently, many questions have arisen from producers regarding performance issues relative to some YieldGard rootworm hybrids and severe lodging that has occurred in certain commercial cornfields. The observations from our experiments will hopefully begin to help us find answers too many of these perplexing questions. Most notably, why was the level of injury in our Urbana experiment much greater than we anticipated? The following is a short set of questions and answers designed to help us improve our understanding of this issue.

### *Has resistance already occurred toYieldGard rootworm hybrids?*

We do not believe so. Keep in mind YieldGard rootworm hybrids were commercially just released for the first time in 2003. It does not seem probable that resistance has occurred this quickly. The FIFRA Scientific Advisory Panel (August 2002) seemed to concur and has suggested that the likelihood of resistance development within the first 3 years of commercialization is unlikely, regardless of refuge size. In April 2003, the U.S. EPA issued a document titled: Event Mon863 Bt Cry3Bb1 Corn Biopesticide Registration

Action Document, http://www.epa.gov/oppbppd1/biopesticides/ingredients/tech_docs/cry3bb½_d_cry3bb1_irm.pdf. in which they point out many of the assumptions underlying model predictions for potential resistance development. If these models have underestimated the actual initial resistance allele frequency, then resistance development could proceed more rapidly. We simply do not have these required data to answer to this question.

### *What steps should be taken if unexpected damage or suspected resistance does occur?*

The FIFRA Scientific Advisory Panel (August 2002a) specifically established four steps a registrant should follow to confirm whether or not resistance may have developed.

1. "request the grower check planting records"
2. "rule out damage from nontarget insects, weather, or other environmental factors"
3. "conduct tests to verify MON 863 was planted and that the correct percentage of plants are expressing"
4. "if plants are MON 863 and damage approaching a 0.5 (node-injury scale) is found on any expressing plant, evaluate roots from the corresponding refuge"

The following paragraph from the April 2003 EPA document (page IID 11) is of particular interest with respect to resistance confirmation.

> "Resistance should be confirmed by a standard diet bioassay or evaluation of root node injury. An insect diet bioassay with the Cry3Bb1 protein that results in a $LC_{50}$ that exceeds the upper limit of the 95% confidence interval of the $LC_{50}$ established from baseline measurements of susceptible populations could be used to confirm resistance. Alternatively, resistance may be confirmed when one or more root nodes of at least 50% of Cry3Bb1 plants grown in the laboratory are destroyed. [Recall that 60% of the roots evaluated from the YieldGard rootworm treatment in Urbana rated 4.0 {1 node destroyed}]. A discriminating concentration bioassay may also be used to confirm resistance; however, this method may take a long time to develop. The August 2002 SAP also recommended investigating the potential of using samples of populations surviving on Bt corn or an evaluation of larval root tunneling to confirm resistance."

Resistance confirmation must be reported to the U.S. EPA within 30 days.

### *What other explanations may account for the loss of performance with the YieldGard rootworm treatment in the Urbana experiment?*

In 2003 (root rating in check 5.45) and 2004 (root rating in check 5.8), we had severe corn rootworm larval injury in our Urbana plots. So, the explanation for the reduced efficacy of the YieldGard rootworm treatment in 2004 cannot be blamed solely on severe corn rootworm larval pressure. However, considerable differences in planting dates occurred between the two growing seasons. In 2003, the Urbana experiment was planted on 13 May (late by today's standards). In 2004, the Urbana study was established on 10 April, nearly 3 weeks earlier. We, as well as other researchers, have established that development and emergence is delayed with the MON 863 event. Is root protection compromised significantly when certain factors converge such as 1) early planting (early to mid-April), 2) delayed corn rootworm development resulting from larvae feeding on MON 863 hybrids, and 3) intense larval pressure (root ratings in the check of two or more nodes of roots destroyed)? Might these factors explain the compromised efficacy in our Urbana experiment as well as in some producers' fields?

### *Does the expression of the Cry3Bb1 protein diminish as the season progresses, compromising root protection in late July and early August?*

As corn plants mature, considerable speculation has arisen concerning the suspected decline in the concentration of the Cry3Bb1 protein within corn plant tissue. YieldGard Rootworm hybrids have been marketed as providing season-long control of corn rootworms. Yet, these marketing claims seem to have been overstated. The lethal concentration ($LC_{50}$) of the Cry3Bb1 protein (necessary to kill 50% of a corn rootworm larval population) is 75 ppm. Dudin et al. (2001) conducted some root expression experiments and determined that Cry3Bb1 expression in corn roots was only 58 ppm. No wonder so many corn rootworm adults emerge from cornfields that have been planted with YieldGard Rootworm hybrids! Other average concentrations of the Cry3Bb1 protein in transgenic (MON 863) corn plant tissue are as follows: young leaf tissue, 81 ppm; grain, 70 ppm; root tissue, 39 ppm; forage, 41 ppm; pollen, 62 ppm; and silks, 10 ppm. Overall survival of corn rootworm larvae that feed on transgenic corn roots (Cry3Bb1, MON 863) is estimated to range from 17 to 62% (U.S. EPA 2002b). Expression of the Cry3Bb1 protein is believed to be greatest in the root tips where newly hatched larvae are feeding. Research conducted at the University of Nebraska (Drs. John Foster and Pete Clark) revealed that first instars of corn rootworm larvae initially feed on root tips of transgenic corn plants (Cry3Bb1, MON 863). Penetration

into roots was not common. Instead, first instars grazed on outer portions of root tissue. This feeding behavior is thought to slow down larval development and ultimately delay adult emergence.

### *Are there critical differences in expression of the Cry3Bb1 protein across hybrids?*

More research is needed to answer this question satisfactorily. However, based upon our observations in 2003 and 2004, we believe the answer to this question is "yes." We believe that expression of the Cry3Bb1 protein in transgenic corn hybrids is likely to differ among hybrids based upon genetic differences (root morphology, root regeneration characteristics) in hybrids and the complex interactions with soil moisture, nitrogen availability, planting dates, and corn rootworm densities.

### *Are some hybrids with less than satisfactory root characteristics poor candidates for the YieldGard rootworm technology?*

Perhaps. Plant breeders with seed companies can most accurately address this question. However, if plant breeders working with entomologists believed that the MON 863 event could be used carte blanche across their portfolio of corn hybrids in the face of any corn rootworm infestation, without any repercussions, they were mistaken. If this assumption was widely accepted, then we believe hybrids with the greatest yield potential may have been selected disproportionately as prime candidates for this insertion with little regard to root characteristics. In 2005, we intend to evaluate this question more thoroughly by examining the level of root injury among several transgenic corn rootworm hybrids at each of our main corn rootworm experimental sites.

As indicated at the outset of this report, we still have much to learn about transgenic insecticidal cultivars and their role in an overall corn rootworm management program. One thing is certain: there continues to be no silver bullet that can be directed at this impressive and resilient insect pest of corn. A final point needs to be made. To date, albeit a short history, transgenic insecticidal corn rootworm hybrids (MON 863, Cry3Bb1) have proven very consistent in their ability to limit corn rootworm larval injury. Despite the "stumble" of certain YieldGard Rootworm hybrids in some locations in 2004, producers should not automatically assume that granular soil insecticides delivered at-planting will deliver more consistent root protection. They, too, are subject to many environmental variables that may affect their performance (Gray and Steffey 1998).

Portions of this report were extracted from two articles published previously in the *Pest Management and Crop Development Bulletin.*

Gray, M.E. and K.L. Steffey. 2003. Transgenic corn rootworm hybrids: a promising IPM tool, yet important concerns linger. Pest Management and Crop Development Bulletin, Issue No. 1, March 20, 2003, University of Illinois, Champaign-Urbana, IL. http://www.ipm.uiuc.edu/bulletin/pastpest/articles/200301b.html

Gray, M.E. and K.L. Steffey. 2004. Transgenic corn rootworm hybrid stumbles in Urbana experiment; some producers also report severe lodging with YieldGard Rootworm hybrids in commercial fields. Pest Management and Crop Development Bulletin, Issue No. 22, September 2, 2004, University of Illinois, Champaign-Urbana, IL. http://www.ipm.uiuc.edu/bulletin/article.php?issueNumber=22&issueYear=2004&articleNumber=1

## References


Dudin, Y.A., B.-P. Tonnu, L.D. Albee, and R.P. Lirette. 2001. Amended report for MSL 16599: *B.t.* Cry3Bb1.11098 and NPTII protein levels in tissue samples collected from corn event MON 863 grown in 1999 field trials. Report No. MSL-17181; an unpublished study conducted by Monsanto Company. Submitted to EPA on May 21, 2001, MRID 454240-01.

Gray, M.E. and W.H. Luckmann. 1994. Integrating the cropping system for corn insect pest management, ch. 12, pages 507-541, in Introduction to Insect Pest Management. R.L. Metcalf and W.H. Luckmann [eds.], John Wiley & Sons, Inc., New York.

Gray, M.E. and K.L. Steffey. 1998. Soil insecticides and root protection: a sure thing, or a roll of the dice each season? pp. 24-28, in Proceedings of the Illinois Agricultural Pesticides Conference. Ill. Coop. Ext. Serv., Urbana-Champaign.

Levine, E., J.L. Spencer, S.A. Isard, D.W. Onstad, and M.E. Gray. 2002. Adaptation of the western corn rootworm to crop rotation: evolution of a new strain in response to a management practice. American Entomologist 48: 94–107.

Meinke, L.J., B.D. Siegfried, R.J. Wright, and L.D. Chandler. 1998. Adult susceptibility of Nebraska western corn rootworm (Coleoptera: Chrysomelidae) populations to selected insecticides. J. Econ. Entomol. 91: 594–600.

Parimi, S.M., E. Scharf, L.J. Meinke, L.D. Chandler, and B.D. Siegfried. 2003. Inheritance of methyl-parathion resistance in Nebraska western corn rootworm populations (Coleoptera: Chrysomelidae). J. Econ. Entomol. 96: 131–136.

Rice, M.E. 2003. Transgenic rootworm corn: assessing potential agronomic, economic, and environmental benefits. Online. Plant Health Progress doi: 10.1094/PHP-2004-0301-01-RV.

Scharf, M.E., L.J. Meinke, B.D. Siegfried, R.J. Wright, and L.D. Chandler. 1999. Carbaryl susceptibility, diagnostic concentration determination, and synergism for U.S. populations of western corn rootworm (Coleoptera: Chrysomelidae). Journal of Economic Entomology 92: 33–39.

U.S. EPA. 2002a. Transmittal of meeting minutes of the FIFRA Scientific Advisory Panel Meeting, held August 27–29, 2002. U.S. EPA, Washington, DC. http://www.epa.gov/scipoly/sap/2002/august/august2002final.pdf.

U.S. EPA. 2002b. Preliminary review of Monsanto's interim insect resistance management plan for *Bacillus thuringiensis* event MON 863 corn rootworm protected field corn. U.S. EPA, Washington, DC. http://www.epa.gov/scipoly/sap/2002/august/7-23-2002_overall_irm_preliminary_review_mon863_corn.pdf.

U.S. EPA. 2003. Event MON863 Bt Cry3Bb1 Corn Biopesticide Registration Action Document. U.S. EPA, Washington, DC. http://www.epa.gov/oppbppd1/biopesticides/ingredients/tech_doc/cry3bb½_d_cry3bb1_irm.pdf.

Zhu, K.Y., G.E. Wilde, R.A. Higgins, P.E. Sloderbeck, L.L. Buschman, R.A. Shufran, R.J. Whitworth, S.R. Starkey, and F. He. 2001. Evidence of evolving carbaryl resistance in western corn rootworm (Coleoptera: Chrysomelidae) in areawide-managed cornfields in north central Kansas. Journal of Economic Entomology 94: 929–934.

# Update on the Range Expansion of the Variant Western Corn Rootworm in Indiana and Illinois

*John Obermeyer and Jared Schroeder*

Until the mid-1990s in Illinois and Indiana, the cultural practice of a corn and soybean rotation was used to prevent root injury from corn rootworm larval feeding in first-year (rotated) corn. Surveys conducted by Steffey et al. (1992) in the late 1980s determined that very few first-year cornfields in Illinois had the potential for economic injury. Injury to first-year cornfields, although not economic, was concentrated in east central Illinois. The recommendation at the time was to continue using a corn and soybean rotation to manage corn rootworm injury. By 1995, the amount of root injury in rotated corn had increased dramatically and was severe in many east central Illinois counties and west central Indiana counties. It was later concluded that producers in east central Illinois had inadvertently selected for a variant western corn rootworm that could circumvent crop rotation by laying eggs in soybean fields the preceding year (Levine et al. 2002). Over the past 9 years, the range of the variant western corn rootworm has spread into central, northeastern, and northwestern Illinois, whereas the western and northwestern regions of Indiana also are at high risk.

## Illinois Situation

Over the past 3 years, on-farm surveys in Illinois have been conducted to determine the extent of root injury in first-year cornfields. The 2004 survey included 24 counties in southern (three counties), western, and northwestern Illinois. Each of these regions is considered to be low risk for the development of western corn rootworm variant infestations. With the cooperation of University of Illinois Extension Crop Systems and integrated pest management (IPM) educators throughout the state, five roots were extracted from each of 10 randomly selected fields within counties from the pre-selected regions. Within each randomly selected cornfield, the observation of soybean stubble was used to confirm that it had been rotated from the previous year. The use of a soil insecticide, seed treatment, or transgenic corn rootworm hybrid was not determined for any of the fields surveyed. All of the roots were brought back to Urbana, IL, washed and rated for injury by using the Iowa State 1-to-6 injury scale (Hills and Peters 1971).

In the 2004 survey, the greatest concentration of first-year corn rootworm larval injury was found in western and the northwestern Illinois. The percentage of plants with root injury ratings greater than or equal to 3.0 (some root pruning, never equivalent to 1 node) for northwestern Illinois are as follows: Bureau, 30%; Carroll, 2%; Henry, 14%; Jo Daviess, 0%; Mercer, 4%; Rock Island, 4%; Stephenson, 0%; and Whiteside, 6%. In western Illinois, injury percentages were as follows: Adams, 0%; Brown, 0%; Fulton, 2%; Hancock, 10%; Henderson, 0%; Knox, 2%; McDonough, 12%; Morgan, 2%; Pike, 7%; Schuyler, 0%; Stark, 72%; and Warren, 8%. The percentage of plants with injury ratings greater than or equal to 3.0 in the southern region of the state was low; however, these data reveal that the variant western corn rootworm is beginning to expand its range to the south: Clay, 6%; Fayette, 0%; and Montgomery, 2%. Additional data from this survey and the past surveys can be viewed at the University of Illinois IPM Web site at http://www.ipm.uiuc.edu/wcrsurvey/index.html.

The 2004 survey suggests that the variant western corn rootworm has now crossed the Illinois River into western and northwestern Illinois. The amount of injury in Adams, Brown, Bureau, Fulton, Henry, Knox, Mercer, Pike, Schuyler, and Stark counties increased from 2003 to 2004. Information concerning the 2003 western corn rootworm variant survey also can be found at the link provided. Although some individual root ratings in counties bordering the Mississippi River were above the economic injury index (root rating of 3.0), overall averages suggest that the variant western corn rootworm had not firmly established itself, as of 2004. In fact, during 2004, reports of severe larval injury in first-year cornfields in this area of the state were scarce. We do anticipate that infestations of the variant western corn rootworm will begin to intensify in some rotated cornfields, even among the counties bordering the Mississippi River as early as 2005.

Monitoring soybean fields by using Pherocon AM sticky traps is still recommended for determining the need for a soil insecticide, seed treatment, or transgenic hybrid. Information concerning scouting procedures also can be found at the University of Illinois' IPM Web site. Jim Morrison, University of Illinois Crop Systems Extension Educator in Stephenson County, monitored eight soybean fields during 2004 in Stephenson County. From southern to northern fields, the average number of beetles captured per trap per day ranged from 4.1 to 1.3. All of the soybean fields were below the established threshold of five beetles per trap per day (O'Neal et al. 2001), but just barely in southern Stephenson County. As population densities of the variant western corn rootworm continue to increase in northern, northwestern, and even southern Illinois, producers should seriously consider the use of Pherocon AM traps in their soybean fields. This approach will enable them to make more informed decisions regarding the use of soil insecticides in their rotated cornfields the following spring.

## Indiana Situation

Sporadic rootworm damage in first-year cornfields in northwestern Indiana counties began to be reported in the early 1990s. Purdue University's initial field investigations were focused on the cause for the presence of western corn rootworm beetles in soybean. Cultural practices, weed presence, or both were targeted as perhaps encouraging the beetles to move into soybean fields later in the season. It became apparent by the mid-1990s that first-year corn rootworm damage was widespread in this quadrant of Indiana and little correlation was seen with soybean tillage, row spacing, weed species and density, and planting date.

By 1996, researchers were comparing sampling tools (e.g., sticky and pheromone traps, and sweep nets) and methodologies in an effort to determine beetle densities in soybean and the potential for root injury in first-year corn. After several years in multiple cornfields, it was determined that the Pherocon AM unbaited trap was the most reliable adult

**Table 1.** Comparison of western corn rootworm sweep net surveys in soybean (number/100 sweeps) and perceived risk.[1]

| | Yr | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **County** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** | **2003** | **2004** |
| | | | | *Very High* | | | | |
| 1) Benton | 322 | 163 | 382 | 448 | 1036 | 196 | 397 | 552 |
| 2) Warren | 1081 | 103 | 352 | 257 | 504 | 265 | 337 | 687 |
| | | | | *High* | | | | |
| 3) Carroll | 466 | 61 | 89 | 356 | 740 | 382 | 78 | 422 |
| 4) Lake | 583 | 12 | 84 | 171 | 182 | 148 | 140 | 629 |
| | | | | *Moderate* | | | | |
| 5) Hancock | 90 | 7 | 60 | 125 | 90 | 127 | 8 | 204 |
| 6) Noble | 258 | 1 | 24 | 26 | 135 | 137 | 42 | 120 |
| 7) Shelby | 44 | 0 | 4 | 20 | 36 | 77 | 2 | 147 |
| 8) Vigo | 3 | 0 | 6 | 14 | 7 | 57 | 35 | 389 |
| | | | | *Low* | | | | |
| 9) Decatur | 7 | 0 | 3 | 9 | 10 | 1 | 0 | 39 |
| 10) Knox | — | 0 | 0 | 1 | 1 | 0 | 7 | 11 |

[1] "Very High" indicates that consistently high numbers of western corn rootworm (WCR) adults have been found in soybean fields. First-year WCR damage is likely and may be severe in parts of or whole fields.

"High" risk indicates that most soybean fields sampled or observed in that area contained high numbers of WCR adults coupled with the fact that first-year corn rootworm damage frequently occurs.

"Moderate" risk means that WCR adult numbers vary from field to field and that significant first-year rootworm damage is expected to be spotty.

"Low" risk areas have consistently low WCR adult numbers in soybean with few, if any, damaged first-year corn fields expected.

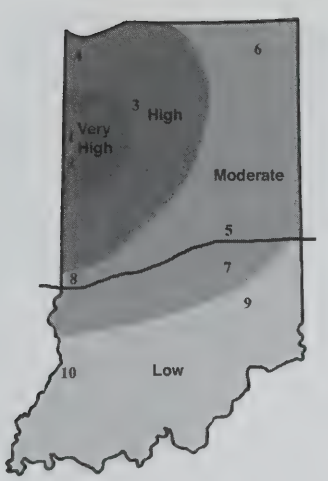



**Figure 1.** Indiana's perceived first-year corn rootworm risk areas and county locations.

trap for predicting the need for a soil insecticide in the following year's corn (Edwards et al. 2003).

Sweep-net sampling is used to monitor rootworm adults throughout Indiana during late July through August. Although this "snapshot" or one-time visit cannot be used to predict economic damage to next-year's corn on a field-by-field basis, it does provide relative abundance estimates of western corn rootworm beetles throughout the state and provides information concerning the movement of the variant. Initially, adult abundance was greatest in northwestern counties of the state. By 1997, significant adult numbers were being detected throughout most of northern Indiana. Rootworm "risk" categories for first-year cornfields were assigned to various regions of the state (Table 1 and Figure 1). Interstate 70 bisects the middle of the state and conveniently made a dividing line from high-to-moderate adult densities in the north, with lower numbers observed in southern counties. Until the 2004 season, counties south of Interstate 70 were considered at low risk to first-year corn rootworm damage.

It has long been assumed that the variant western corn rootworm beetle spreads via prevailing winds. The west/southwesterly summer winds not only have disseminated the variant, first into northwestern Indiana and then throughout northern parts of the state, but also into southern Michigan and northwestern counties of Ohio. This pattern of movement occurred within just a few years. Dispersal has been at a slow "creep" into southern counties of the state. However, in 2004 very impressive adult numbers emerging from severely damaged corn in east central Illinois fields, coupled with northerly winds in late July and early August, assisted in the movement of variant beetles to the south of Interstate 70. Last season's astonishing high adult counts found in this previously low-risk area (Table 1, Vigo County) will challenge producers in southwestern Indiana with decisions regarding their selection of corn rootworm management tactics in first-year corn!

## References

Edwards, C.R., J.L. Obermeyer, L.W. Bledsoe, and C.K. Gerber. 2003. Monitoring and decision rules for western corn rootworm beetles in soybean, E-218-W.

Hills, T.M. and D.C. Peters. 1971. A method of evaluating post-plant insecticide treatments for control of western corn rootworm larvae. Journal of Economic Entomology 64: 764–765.

Levine, E., J.L. Spencer, S.A. Isard, D.W. Onstad, and M.E. Gray. 2002. Adaptation of the western corn rootworm to crop rotation: evolution of a new strain in response to a management practice. American Entomologist 48: 94–107.

O'Neal, M.E., M.E. Gray, S. Ratcliffe, and K.L. Steffey. 2001. Predicting western corn rootworm (Coleoptera: Chrysomelidae) larval injury to rotated corn with Pherocon AM traps in soybeans. Journal of Economic Entomology 94: 98–105.

Steffey, K. L., M.E. Gray, and D.E. Kuhlman. 1992. Extent of corn rootworm (Coleoptera: Chrysomelidae) larval damage in corn after soybeans: search for the expression of the prolonged diapause trait in Illinois. Journal of Economic Entomology 85: 268–227.

# Aquatic Weed Management

*Carole A. Lembi*

## What You Need to Know BEFORE Using a Chemical

1. Identify the weed

   The two major groups are the algae and the flowering plants.

   *Algae* (3 types):

   Those that cause green water

   The mat-formers

   Chara (can be confused with submersed flowering plants because it has stems and leaves)

   *Flowering plants* are categorized by where they live (submersed, free-floating, rooted floating, emergent)

2. Always read the herbicide label. Particularly note the following:

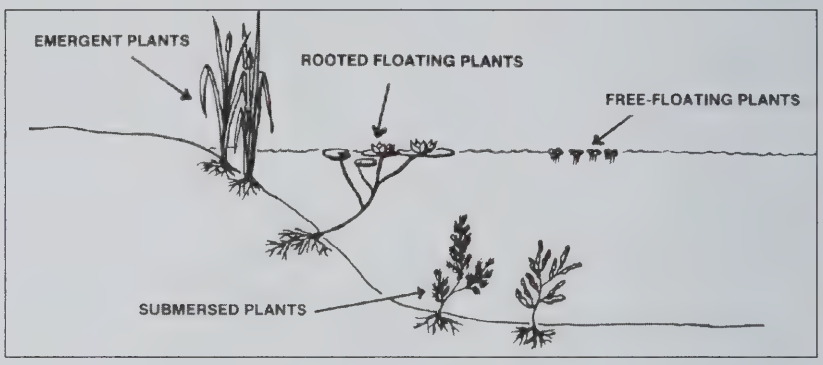
   A. Restrictions on use of water following herbicide treatment (e.g., for irrigation, livestock watering, fishing)

   B. Dosage calculation

3. Timing of treatment is important: late spring and early summer are best. DO NOT treat when the pond is heavily infested with the weeds or algae. Treating and killing all this vegetation may cause oxygen depletion and a fish kill.

4. Water temperature in the area of treatment should be at least 60°F.

5. Retreatment is usually needed, either the year of application or the next year. We do not have any permanent solutions to getting rid of aquatic weed growth!




## Aquatic Herbicides/Algicides

### *Algae*

Copper sulfate

Copper chelates (e.g., Cutrine Plus, Captain)

GreenClean

Hydrothol 191 (liquid or granular): recommended primarily for certified applicator use

### *Flowering plants*

Submersed (underwater) plants

- Aquathol K (liquid)
- Aquathol Super K (granular)
- Reward (liquid)
- Sonar or Avast! (liquid or pellet)

Submersed (underwater) plants, specifically Eurasian watermilfoil

- Renovate 3 (liquid)
- Navigate or Aqua-Kleen (granular)
- Sonar or Avast! (liquid or pellet)
- DMA 4 IVM (liquid)

Free-floating plants such as duckweed and watermeal

Reward (liquid)

Sonar or Avast! (liquid)

Emergent (shoreline) plants (NONSELECTIVE: all plants, including broadleaves and grass-like plants such as cattails = glyphosate)

Rodeo, AquaMaster, AquaNeat, Aqua-Pro (liquids); these require adding a wetting agent (surfactant) to the solution

Glyphomate 41 (does not require addition of surfactant)

Emergent (shoreline) (SELECTIVE: broadleaved plants such as purple loosestrife; should not affect grasses and grass-like plants such as cattails)

Renovate 3 (liquid)

DMA 4 IVM (liquid)

Emergent: specific recommendation for control of Phragmites (from Army Corps of Engineers):

6 pt/acre glyphosate with 0.5% (v:v) surfactant during the mid to late flowering stage. Spot treatments should be made during the year following treatment.

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HABITAT, a new herbicide, received EPA registration January 2004. Recommended for duckweed, cattails, Phragmites.

# On-Farm Research: If I Like the Results, It Must Be Science

*Emerson D. Nafziger*

Many crop producers and crop input providers in Illinois run "tests" to see whether crop inputs produce yield increases or control pests like they're advertised to do. Such tests may be called "plots" or "strips" or "side-by-sides," and they take a lot of different forms, from simply paying attention to when hybrids or varieties change during planting so yields within each can be measured, to more organized trials with multiple locations and replication. Such efforts are valuable in a number of ways: they provide evidence of visual responses that may be described for some inputs; they can provide yield data to help define whether using a certain input might increase profits; and they provide a good outlet for the healthy curiosity that many producers have about how crops grow and respond to management factors. In recent times, such work has even become easier to do, thanks to yield monitors, more precise controllers on equipment, and the increasing use of guidance and positioning technology that makes it easier to put things in the field where we want them, and also to keep track of where they are.

It is helpful to define what we mean by "research" in the context of this workshop. For our purposes, the word means "applied" research, defined as follows:

> *Applied research is a set of planned comparisons carried out over an adequate number of fields and years, with results accumulated and analyzed to allow us to predict the response from tested inputs when we use them in the future.*

The emphasis here is on prediction, and prediction will usually include an estimate on how often responses will be different than the average response, and how wide the range of responses might be. Is this "science"? An activity designed to use present observation to predict future outcomes is science, so yes, this qualifies. Of course, there is "bad" science, which usually means that outcomes are decided beforehand and "results follow," or may simply mean that work was sloppy or inadequate such that what we found does not predict the future.

As an example, we might test a micronutrient mixture (Brand X) on soybean, and end up making a statement like this: "We expect Brand X to return a profit of $3.50 per acre on average, but we found a positive return to its use only 70% of the time, and the return ranged from –$4.50 to +$9.00 per acre." It's great when we can add more modifiers to such statement, for example, that it more often returns a profit on soils with less organic matter. Unfortunately, finding such clearcut differences is rare, in part because we usually can't test in enough different fields often enough to make such distinctions. We can more often see differences based on what the weather happened to be like during the season, but until we have weather forecasts that can truly predict what the season will be like before we have to decide whether to use an input, knowing how weather will affect a response does us little good.

Although the interest in doing on-farm comparisons of different inputs is a healthy one, it brings with it the danger that conclusions from such work might be "wrong," which we will define here as "not accurately predictive of future response." This can lead to decisions that end up costing money rather than returning profit, though we can "miss low" and underestimate return as well. Many producers recognize this as a potential problem, and some tend to have more skepticism about their own results than might be warranted: it's not at all unusual to have a producer start describing what he's found with phrases such as, "I don't know if I'm doing this right ..." or "This isn't scientific, so I don't know if it means much ..." Maybe if the university types were honest, we ought to start using such phrases a little more often ourselves, but I do think that many producers could have more confidence in what they're doing and seeing. There's real value in close and thoughtful observation, and in many cases the quality of conclusions a producer might make from an on-farm comparison can often override flaws that might exist in an experimental design.

One of our goals in this workshop is to continue to "demystify" the process of drawing conclusion from on-farm comparisons and hence to make them more valuable to

producers and to those who advise producers. Making such comparisons is not an activity reserved for "scientists," but rather an opportunity for anyone who wishes to become more observant and better informed. On the other hand, there is a real need for everyone involved to understand the limitations of on-farm research. Such limitations vary with the type of comparison being made, but they start with an appreciation of the fact that response to most inputs is highly conditioned by the weather and how weather is interacting with crops in a particular season. There is simply no getting around this, no matter how many "testimonials" there might be to give the impression that some products always work. Unfortunately, the pressure to sell may lead some who do such work to delete data that don't support sales, or otherwise manipulate the process. Lack of neutrality, real or imagined, continues to undermine the value of on-farm research.

Just because the response to an input might vary with the season, with soil type, or even by crop or crop variety does not rule out that input's being economically useful. It does, however, mean that pinning down an expected return to use of the input requires a great deal of work; if response is highly variable among seasons, then we need a lot of seasons (locations separated by some distance can substitute for lots of years in most cases) to be able to predict the response the next time we use it. If soil type strongly affects performance, then we need to test over a lot of soil types, or restrict its use to those soils types on which it's consistently worked well. There just are no easy answers to this problem, but there's also no good alternative to extensive and careful testing; just giving up on a promising input, or deciding to use it because it works "once in a while" will often lead to loss.

We will provide some examples of ways to test inputs and look at results during the workshop. Here are some points that may help ease the way for many Illinois producers and those who advise them to do their own on-farm comparisons of crop inputs. For simplicity, we'll direct these to comparisons with only two "treatments," for example, untreated versus treated, or two varieties compared with one another:

1. Approach this exercise with complete neutrality. If you already "believe in" an input, to the extent that you will believe it provided a benefit even when your results don't show that, then just use it and skip the comparison. Biased trials and "selected" results that come from non-neutral trials mislead rather than inform.

2. You need to have treated and untreated areas next to each other in to know that the treatment did anything. The statement "I used this material and I got better yields than I expected" is more of a "belief statement" about an input than it is a comparison. No matter how good your sense of what yield to expect from a field, a measurement against your expectation is not precise enough to tell us much, especially when weather and pests deal us surprises almost every year, making it impossible to know what yields "should" have been.

3. Without replication, consisting of four to eight pairs of strips, one treated and one untreated strip in each pair, you will always wonder whether any difference (or lack of difference) you found might have been due to the luck of where the treated area was placed. Replication also can consist of paired strips in a number of different fields.

4. A single, replicated trial in a field one year will describe what happened better than it will predict what will happen next time or in another field. Trials need to be done over seasons and fields, or results will not predict for future seasons and fields. By the same token, results from a trial done in the best, most uniform soil that you farm will predict for the best, most uniform parts of the fields that you farm, but probably not for less-productive areas.

5. Apply treatments carefully, in strips wide enough to take full combine passes for yield, and be sure to remember where you put what. Planting a 6-ft length of PVC pipe (use a soil probe to plant it) in the middle of the end of treated strips is a good way to know where strips are, especially if they weren't marked using global positioning system. If driving over the crop is a concern, you will want to drive over the untreated strips to duplicate the damage on treated strips. Randomizing the order of strips (by tossing a coin, with heads meaning treat the first strip of that pair and tails to treat the second strip) is good, but alternating treated and untreated strips doesn't usually cause much bias (unfair advantage to one treatment), especially if the field is relatively level and uniform.

6. Record yield carefully in each strip. Yield monitors usually work well for many comparisons, especially when treatments don't affect grain moisture or test weight very much. Some people prefer the direct measurements provided by weigh wagons.

7. Don't fret too much about statistics; if the trial was done well and without bias, just averaging yields from treated and untreated strips will provide a reasonable answer. Statistics can put some probabilities to the results, telling us how much confidence we can have that any difference was actually caused by the treatment. This is usually important in meeting our research goal.

8. Use all of the results you get, unless there was an obvious mistake. Unfortunately, throwing out strips that don't agree with a bias is a great way to "cook" results, and it is probably better not to even have replications (or a trial

at all) if there's any possibility that this could happen. Why even bother to go to the trouble of doing on-farm comparisons if we already "know" what the results will be?

If anyone does strip trials such as those described here and in the workshop and would like to share results and have some statistical work done on them, I am willing to respond to such requests. E-mail the data to me on a spreadsheet (Excel), along with a description of what was done, and I will respond.

One way to help sustain Illinois as a crop-producing power would be to develop a network of interested and involved producers and their advisers committed to neutral testing of available inputs. We have the tools and abilities to make this happen, and now is the time to get started.

# Alfalfa Production Management—Steps to Greater Profits

*David Feltes, R.G. Hoeft, and James Morrison*

## Cultural Practices

*Jim Morrison*

This portion of the seminar focuses on various cultural practices other than soil fertility that impact the profitability of alfalfa hay production. The material addresses some frequently asked questions.

### *Variety Selection*

When selecting varieties, consider yield potential, persistence, winterhardiness, disease and insect resistance, forage quality, and soil characteristics in the fields to be planted. The University of Illinois Department of Crop Science alfalfa variety trial (located at Belleville, Freeport, and Urbana) results are available yearly in the booklet *Forage Crop Variety Trials in Illinois* and on the Web at http://vt.cropsci.uiuc.edu/forage.html. Yield data are posted to the Web site after each cutting (typically a 30-day cutting schedule), including the seeding year.

Yield ratios for a four-cut and three-cut program are shown in Table 1. These figures provide a guide for the yield by each cutting as a percentage of the yearly total. Corresponding numbers from Freeport over the past few years were 37, 23, 22, and 18% from the first, second, third, and fourth cuttings, respectively.

At the Freeport site, the average of the five top-yielding varieties was 1.4 tons per acre per year more than the check variety (Vernal) over three production years.

Knowing the yield in the seeding year is also important. At Freeport and Urbana, the average range in yield (from high to low) between varieties in the seeding year was 1 ton per acre. The five top-yielding varieties produced an average of 0.8 ton per acre more than the check variety (Vernal).

Seed costs amount to only 6 to 8% of the total 4-year cost of producing alfalfa hay that yields 2.5 tons per acre in the seeding year and 6 tons per acre in each of the succeeding 3 years.

**Table 1.** Yield ratio for four- and three-cut programs.

| Cutting schedule | Yield ratio |
|---|---|
| 4-cut | 9:7:5:3<br>(38, 29, 21, and 13% of yearly total yield) |
| 3-cut | 7:5:3<br>(47, 33, and 20% of yearly total yield) |

Alfalfa varieties can be compared from one or multiple states, years, or a combination at the University of Wisconsin Web site at http://www.uwex.edu/ces/ag/alfalfa/index.cfm.

### *Seeding Date*

A spring seeding date (when soil conditions first allow a seedbed to be prepared) tends to be more successful in the northern half of Illinois, whereas late-summer seeding is more successful in the southern one-third of the state. Benchmark dates for late summer seeding are August 15, August 30, and September 15 for the northern one-quarter, central one-half, and southern one-quarter of Illinois, respectively. Late summer-seeded alfalfa needs at least 6 weeks of growth before the first killing frost. The crop needs this time to become well established (approximately 6 in. of top growth) so a crown can be developed before dormancy. Late summer seedings need sufficient soil moisture and good seed-to-soil contact.

### *Seeding Rate*

Seeding rates, expressed as pounds of pure live seed (PLS) per acre, are indicated in the 23rd edition of the Illinois Agronomy Handbook, which is available at Extension offices and online at http://www.aces.uiuc.edu/iah/. From 12 to 15 pounds of PLS per acre is a general recommendation, given good soil conditions and seeding equipment. This range also reflects that typically no more than one-

third of the sown seed produce seedlings and one-half of these survive the first year.

Recent research at Missouri and Pennsylvania found that increasing alfalfa seeding rates above 15 pounds per acre provided no measurable long-term benefit. Seeding rates greater than 15 pounds per acre initially had higher plant densities, but these differences did not persist beyond 6 months after planting.

### *Autotoxicity*

Alfalfa produces autotoxic chemical(s) that reduce germination of new alfalfa seedlings and inhibit the root system. Long-term yield reduction of 8 to 29% due to autotoxicity also has been documented, even when plants looked normal.

Established plants can severely reduce the germination and growth of new seedlings within an 8-in. radius from the older plant. New seedlings within a 16-in. radius from the older plant may survive, but they are often low yielding. Trying to "thicken up" an existing stand that had just one plant per 2.8 ft2 decreased yield by nearly 30%. If the existing stand has less than 0.2 plants per square foot, establishment of new plants could be successful, but consider competition for light and moisture from established plants.

Because young plants less than 1 year of age produce lower quantities of the autotoxic chemical than older plants, one can reseed new seeding failures any time up to 1 year after initial seeding. Research has shown that 1-year rotation out of alfalfa is sufficient for successful reestablishment of alfalfa. Red clover is tolerant to alfalfa autotoxins.

### *Stand Evaluation*

Alfalfa stem density or stem count is a better predictor of potential yield than plants per square foot. Stem counts can be taken any time plants are 4 to 6 in. in height by counting any stem that would be cut by the mower. Optimum number of stems are 55/ft2. If there are less than 39 stems/ft2, consider rotating the field out of alfalfa. Stems counts should ideally be taken in the fall, and a few plants should be dug at the same time to assess root health. If assessing the stand in the spring before much growth has occurred, one may need to count the number of plants per square foot. New seedings should have 25 to 30 plants/ft2. Two-year-old stands with six or fewer plants per square foot or 3-year-old stands with three or fewer plants per square foot will not yield well.

### *Predicting First Harvest*

The first cutting is important for many reasons. As shown above, approximately 40% of the total yield comes from the first cutting, and quality changes most quickly before first cutting. Due to the variation from year to year, one should not base harvest date on a calendar date.

Predictive equations of alfalfa quality (PEAQ) can help producers and agriculture dealers monitor quality, plant growth, and decide the date of first cutting. PEAQ predicts fiber and relative feed value (RFV) based on the height and stage of maturity of standing alfalfa.

The Web site at http://peaq.outreach.uiuc.edu/ illustrates how to calculate PEAQ, and it also reports PEAQ values for Illinois by region and by county, and explains how one can enter and track their PEAQ values. Many alfalfa seed companies produce a PEAQ measuring stick that indicates RFV of standing alfalfa based on the height and stage of maturity. Producers need to balance the PEAQ technique with short-term weather forecasts.

### *Date for Last Harvest*

The last hay harvest during the growing season should be in late August–early September for the northern one-quarter of Illinois, by September 10 for the central portion, and by September 20 for the southern one-quarter. These dates are based on the guideline that alfalfa needs about 6 weeks of regrowth after a harvest and before a killing frost to allow food reserves to build up in the taproot and crown.

### *Frost and Dormant Harvest*

There is no known toxic compound in alfalfa that results from a frost. One should wait 1–2 days after a frost until the frosted parts of the plant dry before grazing alfalfa to reduce the laxative effect and bloat potential. A killing frost for alfalfa is generally considered to be 24°F for a few hours. If short of forage, a harvest can be made from an established stand after a killing frost or after mid-October (for northern Illinois), but leave a 6-in. stubble so the stems can catch snow and remain above any ice layer. Studies have found that taking a late fall cutting (after October 15) reduces yield of first cutting the next spring. Soil fertility, disease resistance, previous cutting schedule, and snow cover affect how a late fall cutting impacts winter survival.

### *Fall Dormancy and Winterhardiness*

There is a weak relationship between these factors. Varieties are rated or scored for their winterhardiness (1, superior survival and 6, no survival). The higher the fall dormancy number (scale of 1 to 10), the quicker the spring greenup and the quicker it regrows after cutting. It is desirable to have a fall dormancy of 4–5 with a winterhardiness of 1 or 2. Critical soil temperature is 15°F at the crown. Michigan data suggest that snow cover of 4 in. adequately protects alfalfa from winter injury. This amount of snow can greatly reduce the temperature variation between day and night and insulate the soil resulting in temperature increases of 10°F.

### *Effect of Wheel Traffic*

Wheel traffic can reduce yields due to broken stems, crown damage, and soil compaction. Driving on a field soon after harvest reduces yield damage, so it may be best to make silage from higher yielding fields and hay from lower yielding ones. Studies have shown a 10 to 15% decrease in yield due to traffic, although this depends on timing, where wheel traffic at 2 days caused significantly less yield reduction than at 5 days. Genetic differences exist for traffic tolerance among varieties.

### *Additional References*

In addition to the Web sites mentioned above, other references include the following:

- Illinois Agronomy Handbook, 23rd ed. (University of Illinois Extension)
- Alfalfa Management Guide, NCR 547 (North Central Regional Extension publication)
- 2005 Illinois Agricultural Pest Management Handbook (University of Illinois Extension)

## Hay and Pasture Fertilizer

*R. G. Hoeft*

Forage crops, whether used for hay or pasture, like all other plants require a total of 16 nutrients to sustain productivity. Fortunately, most midwestern soils inherently supply the majority of these nutrients. The list of nutrients not supplied in adequate amounts for optimum production are for the most part limited to nitrogen (N) (grass crops only), phosphorus (P), potassium (K), and to a lesser extent sulfur (S) and boron (B). To enhance the availability of applied as well as inherent nutrients, soil pH should be maintained at the proper level for the species being grown. The objective of this report is to evaluate the impact of N, P, K, S, B, and soil pH on stand longevity and the quantity and quality of forage crops.

### *Soil pH*

Maintenance of soil pH between 6.0 and 7.0 optimizes production of most crops. Raising that level to 6.5 often enhances productivity of alfalfa and increases the stand longevity (Peters et al. 2003). In this recent work from Wisconsin, when pH was maintained in the range from 6.5 to 7.0, with stand measured as crown count, the stand was maintained at between seven and eight plants per square foot over the 4 year of the study, compared with less than one plant per square foot when pH was less than 5.0. Increasing soil pH from less than 5 to 6.5 increased alfalfa yield by 250 to 400%. At low pH levels, there was little yield response to K, but when the soil was adequately limed substantial response to topdressed K was observed. Soil pH had minimal effect on K and magnesium (Mg) concentration in alfalfa, but it significantly increased calcium (Ca) concentration by 25–30%.

Maintenance of optimum pH levels for pastures is essential to maximize production, but an oft-neglected practice. Although most grasses and some legumes do well at pH 5.7–6.0, soil pH should be maintained at 7.3 or higher if the producer wants to maintain alfalfa in the pasture. Before seeding or renovating pastures, be sure to thoroughly incorporate the recommended rate of lime. Once the optimum pH level is established, periodic surface applications of lime can maintain pH for several years.

### *Nitrogen*

For grass hay, the species grown, period of use, and yield goal determine optimal N fertilization (Table 2). If extra spring growth can be used, make the first nitrogen application in March in southern Illinois, early April in central Illinois, and mid-April in northern Illinois. If spring growth is adequate without extra nitrogen, the first application may be delayed until after the first harvest to distribute production more uniformly throughout the summer. Total production likely will be less, however, if nitrogen is applied after first harvest rather than in early spring. Usually, the second application of nitrogen is made after the first harvest; to stimulate fall growth; however, this application may be deferred until August or early September.

**Table 2.** Nitrogen fertilization of grass hay.

| | Time of Application | | | |
|---|---|---|---|---|
| **Species** | **Early spring** | **After first harvest** | **After second harvest** | **Early September** |
| | Nitrogen (lb/acre) | | | |
| Kentucky bluegrass | 60–80 | | | (see text) |
| Orchardgrass | 75–125 | 75–125 | | |
| Smooth broomegrass | 75–125 | 75–125 | | 50* |
| Reed canary grass | 75–125 | 75–125 | | 50* |
| Tall fescue for winter use | | 100–125 | 100–125 | 50* |

*Optional if extra fall growth is needed.

Legume-grass mixtures should not receive nitrogen if legumes make up at least 30% of the mixture. After the legume has declined to less than 30% of the mixture, the objective of fertilizing is to increase the yield of grass. The suggested rate of nitrogen is about 50 lb/acre when legumes make up 20 to 30% of the mixture.

### *Pasture Fertilization*

The producer must consider the productivity of the grazing animals, the plant species present, and the management level and goals for the pasture. If legumes comprise 30% or more of the sward, do not apply nitrogen fertilizer because an adequate amount will be contributed through fixation. If the legume portion is less than 30%, grass probably will respond to nitrogen fertilizer. If applying 100 lb nitrogen/acre, apply the first 50 lb in early to mid-June when the spring flush of grass growth is over, and apply the second 50 lb in late July to early August. Because early season growth is generally excessive, an early spring application is not suggested unless the first harvest can be efficiently grazed or will be harvested as hay or silage. Nitrogen application early in the season can make grazing management of the spring flush more difficult.

Source of nitrogen is important for summer application. Use a dry nitrogen source, ammonium nitrate, ammonium sulfate, or urea. If urea is the product of choice, application within 1 to 2 days before receipt of at least 0.5 in. of precipitation or use of a urease inhibitor will reduce the potential for volatility. Do not apply liquid urea-ammonium nitrate solutions to an actively growing pasture.

### *Phosphorus*

Soil test results will accurately predict the need for supplemental P fertilizers. If soil test P levels are below 40 lb/acre, fertilizer should be applied to build the test to at least 40 lb. Generally, 9 lb of P2O5 will increase the soil test 1 lb. In addition, apply a maintenance application equivalent to 11 lb of $P_2O_5$ per ton of hay produced. Maintenance application should be made to all fields that have a P test less than 70.

### *Potassium*

As with phosphorus, the soil test accurately predicts K needs for forages. If test levels are below 300 lb K/acre, apply enough to build the test (4 lb of $K_2O$ per 1 lb of soil test increase) plus enough to replace the K removed in the forage (50 lb of $K_2O$ per ton of hay harvested). Maintenance applications should be made on all fields testing less than 400 lb of K.

Nearly 20% of soil and alfalfa samples collected from alfalfa fields in northwestern Illinois had K concentrations in the tissue below the desired level. In nearly all these fields, the sample sites had correspondingly low K soil test levels. Unfortunately, this problem is often observed in acres of intense alfalfa production because many producers do not recognize the large amount of K that is removed in a high-yielding alfalfa crop and consequently do not apply enough supplemental K to meet crop removal.

Whereas the addition of K has the potential to increase yield, addition of too much K could result in a reduction in forage quality. Increasing soil test levels beyond that needed for optimum yield or annual application greater than needed decreased crude protein and increased acid detergent fiber (Kelling and Speth 1998). High K soil test levels also increased K concentration in the plant tissue. Milking dairy cows can readily use high potassium concentrations in forage, but feeding high K forage (>2.5% K) immediately (approximately 3 weeks) before calving increases the potential for milk fever.

### *Sulfur*

Sulfur deficiency, although rare in Illinois, has been observed with more frequency on alfalfa in northwestern Illinois. In a recent survey, 6% of the fields sampled had low S concentration in the tissue. Reduced $SO_2$ emissions resulting from increased air quality standards undoubtedly result in an increase in S deficiency, particularly on alfalfa. When the deficiency exists, application of 20 lb S/acre optimizes alfalfa production.

### *Boron*

Boron deficiency is one of the most frequently observed problems on alfalfa. More than 15% of alfalfa samples collected from northern Illinois had low boron concentrations. Symptoms of boron deficiency typically occur on the second and third cuttings of alfalfa and are especially pronounced during droughty periods in some areas of Illinois. Application of boron on soils with less than 2% organic matter is recommended for high alfalfa production in Illinois. If you suspect boron deficiency, submit a plant sample for laboratory analysis and take soil samples. As a guide, 1 to 2 lb of boron per acre can be applied yearly to sandy soil. On heavier soil, 3 to 4 lb of boron per acre can be applied in the first hay year. Do not apply boron to alfalfa the year preceding corn.

### *References*

Kelling, K.A. and P.E. Speth. 1998. Alfalfa response to K rate, source, and time of application. Proceedings of the North Central Extension Industry Soil Fertility Conference 14: 110–118.

Peters, J.B., K.A. Kelling, P.E. Speth, and S.M. Offer. 2003. Alfalfa yield and nutrient uptake as affected by pH and applied K. Proceedings of the Wisconsin Fertilization, Aglime, and Pest Management Conference 42: 323–332.

## Insects in Alfalfa

*David Feltes*

### *Blister Beetle*

Blister beetles in alfalfa hay can cause sickness and death in livestock, particularly horses. Blister beetles contain cantharidin, a chemical irritant that can blister internal and external body tissues. There are few documented cases of fatalities in cattle and sheep, but cantharidin contaminated hay is deadly to horses. The amount of cantharidin necessary to kill a horse is 1 milligram per kilogram of horse weight.

Blister beetles are an occasional pest in hay production especially in drought years or the year after a drought. There are several species of blister beetle present in the Midwest, including the black, striped, margined, and gray. Blister beetles vary in toxicity depending on species. Scouting is misleading because blister beetles tend to cluster and may concentrate in parts of a field but be absent from other parts. Cantharidin is a very stable compound; dead beetles are as deadly as live beetles, thus making sprays generally not effective.

Blister beetle populations tend to build throughout the season, so if they are a concern, first crop and early second crop hay generally should be fed to horses. Another management options is to bale the first two or three rounds in a field and not feed this to horses. Harvesting fields before flowering and maintaining weed-free stands reduces beetle populations.

### *Clover Leaf Weevil*

Clover leaf weevil larvae eat alfalfa leaves, usually beginning with the foliage around the base of the plant. Crop injury occurs mostly before first cutting and is considered insignificant compared with damage caused by the alfalfa weevil. The larvae are active at night and on cloudy days. During sunny days, they hide around the base of the plant in crop debris.

Adult clover leaf weevils are two to three times larger than alfalfa weevil adults and very similar in appearance to alfalfa weevil adults. Clover leaf weevil adults can damage new regrowth after a cutting, just like alfalfa weevil adults. The insect normally leaves the fields shortly after the first cutting and returns in late summer to feed and lay eggs before winter. There is one generation per year, and they over winter mostly as partially grown larvae.

### *Alfalfa Weevil*

Larvae chew and skeletonize leaves with large larval populations being capable of defoliating entire plants, thereby giving the field a grayish cast. Damage normally only occurs to the first cutting, but both larvae and adults may damage regrowth when populations are high, resulting in both yield and stand loss.

Larvae pass through four instars and after the last instar, spin cocoons on plants or in curled up leaves that have fallen to the ground. The pupal stage requires 1 to 2 weeks for completion. After adults emerge from their cocoons, they feed for 1 or 2 weeks and move out of the field to sheltered areas to spend the summer.

In southern areas, significant egg laying occurs during the fall with the majority of the eggs surviving and thus exposing those fields to early larval damage in the spring. Weevils also lay eggs in the spring in southern fields, giving rise to two peak feeding times by the larvae. In northern areas, fall laid eggs do not survive well, so any damage incurred is from spring-laid eggs. Larval damage in northern areas is likely only if the harvest is delayed. Injury to alfalfa in the northern portion of Illinois is most likely to occur on regrowth after the first cutting and is caused by both the adult and larval stage of the alfalfa weevil. Treatment for this insect is warranted when 25–40% of the tips are being skeletonized and there are three or more larvae per stem.

### *Potato Leafhopper*

Potato leafhoppers do not over winter in Illinois; they migrate into the state from the southern Gulf Coast states on southerly winds in the spring. Female potato leafhoppers live approximately 1 month, and during this time insert two to three eggs per day into the stems and larger leaf veins of suitable plants. Nymphs hatch in 7–10 days and in approximately 2 weeks become adults. The entire life cycle requires about 1 month to complete.

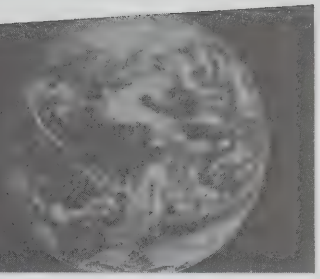
Damage to foliage results from the removal of sap and under dry conditions, yield may be dramatically reduced. Severe potato leafhopper injury can reduce both the protein and vitamin content of alfalfa. The damage potential of potato leafhopper is greatest during dry years. Field margins are normally the first part of an alfalfa field to display injury from potato leafhopper and are frequently the most severely damaged portion of the field. The second and third cuttings of hay in Illinois are most at risk for damage by the potato leafhopper.

A 15-in.-diameter sweep net is required to effectively monitor for leafhoppers. Hay should be sampled at a minimum of once per week after the first cutting. Wet fields should not be sampled because the results obtained may not be a reliable estimate of the damage potential within a field. Twenty sweeps should be taken in five different areas of the field, and the number of nymphs and adults recorded. Because both nymphs and adults can damage alfalfa,

it is important to count both. Alfalfa height and leafhoppers per sweep are used to make a treatment decision. The smaller the alfalfa, the fewer leafhoppers per sweep it takes to cause economic damage.

There are other insects that can damage alfalfa, but I have chosen to highlight those that I receive the most questions about. A more in-depth discussion of economic thresholds plus products recommended for use to control the pest once the economic threshold is reached can be found in the *Illinois Agricultural Pest Management Handbook and the Field Crop Scouting Manual.*

# The Quality of Soil Testing: Expectations, Perceptions, and Reality



*Robert O. Miller*

# The Importance of Spray Droplet Size for Ground and Aerial Applications

*Scott Bretthauer and Loren E. Bode*

The size of the spray droplets created during both ground and aerial applications plays a major role in determining the success of the application. Droplet size affects coverage of the target and thus influences the efficacy of the treatment. Droplet size is also a determinant in the risk of drift occurring. Small droplets provide better coverage of the target but are more likely to drift, whereas large droplets provide reduced coverage but are not as likely to drift. Aerial and ground applicators use different techniques and equipment to control droplet size during an application.

## Droplet Size Measurement and Classification

To properly select and set up both ground and aerial spray equipment, it is important to understand how droplet size is measured and described. The droplet size needed for an application and what nozzle type, size, and operating pressure will create that droplet size can then be determined. There are several ways to describe the droplet sizes produced by a nozzle.

Spray droplets are measured in micrometers (μm). One micrometer is equal to 1/25,000th of an inch. Droplet size is given as the diameter of the droplet. The droplet size at which spray drift becomes a major concern is around 150 μm. Droplets smaller than 150 μm in diameter are more likely to drift, whereas droplets with a diameter larger than 150 μm are not considered a high risk for drift. Keep in mind 150 μm is not an exact cut-off point; it is a general guideline. For comparison, a human hair is about 100 μm in diameter (Table 1). Not all droplets produced by an individual nozzle are the same size. A nozzle produces a range of droplet sizes known as the droplet size spectrum. This means even if you are using a nozzle with a large orifice that is primarily producing large droplets, there is still a portion of the spray droplets that are small and thus prone to drift.

A common method used to describe the droplet spectrum of a nozzle is volume median diameter (VMD). VMD is the droplet size at which one-half of the total spray volume coming out of the nozzle is contained in droplets larger than the VMD and one-half of the spray volume is contained in droplets smaller than the VMD. The problem with using VMD to describe the size of droplets produced by a nozzle is that it does not directly address the small droplets, which are the ones most likely to drift off-target. For example, a nozzle with a VMD of 510 μm contains one-half of its total sprayed volume in droplets with a diameter greater than 510 μm and the other half in droplets smaller than 510 μm. This fact does not provide adequate information about the number of droplets smaller than 150 μm, which are the ones that are most likely to drift off-target.

Another way of describing the droplet sizes produced by a nozzle is to give the percentage of spray volume contained in droplets smaller than a specific diameter, usually 150 μm. This method of description directly addresses droplets small enough to be at risk for drift. For example, a nozzle may be measured to produce 2% of its total spray volume in droplets smaller than 150 μm in diameter, which means that only a small portion of the total volume sprayed by this nozzle is contained in droplets at risk for drift. This type of description, however, does not reveal any information about the size of the remaining droplets produced by the nozzle, which is necessary to determine potential coverage of the target for an application.

**Table 1.** Diameters of various items for purposes of comparison to spray droplet size.

| Item | Diameter (μm) |
|---|---|
| Pencil lead | 2,000 |
| Paper clip | 850 |
| Staple | 420 |
| Toothbrush bristle | 300 |
| Sewing thread | 150 |
| Human hair | 100 |

**Table 2.** ASAE droplet spectrum classification categories, symbols, and VMD ranges.

| ASAE Standard S-572 droplet spectrum category | Symbol | VMD (μm) |
|---|---|---|
| Very fine | (VF) | < 150 |
| Fine | (F) | 150–250 |
| Medium | (M) | 250–350 |
| Coarse | (C) | 350–450 |
| Very coarse | (VC) | 450–550 |
| Extremely coarse | (XC) | >550 |

The most practical means of describing the droplet sizes produced by a nozzle is categories of droplet sizes based on the entire droplet size spectrum, not just the VMD or the percentage of volume in small droplets. The spray classification system used is the American Society of Agricultural Engineers (ASAE) standard S-572: Spray Nozzle Classification by Droplet Spectra. This classification system has six categories (from small to large): very fine (VF), fine (F), medium (M), coarse (C), very coarse (VC), and extra coarse (XC). Using these categories, an applicator can select a nozzle and operating pressure that produce a specific droplet size spectrum. The droplet size spectrum required for a job is based on the type of pesticide being applied and is stated on the label. Table 2 shows the six droplet spectrum categories and their VMD ranges. Keep in mind that even though a VMD range is given for each category, the classification is based on the entire droplet spectrum produced by a nozzle, not just the VMD. The VMD is given for reference. Table 3 shows recommended droplet spectrum categories for various applications.

## Drift

There are two types of drift. Particle drift is the off-target movement of spray particles, and vapor drift is the off-target movement of evaporated gases. Wind speed and direction strongly affect the likelihood of particle drift. The stronger the speed, the further spray droplets can be carried off target. Wind direction determines where these droplets will travel. An applicator has no control over these factors, only the ability to decide whether or not to spray if the wind speed is too great or if the wind is blowing toward particularly sensitive areas. Droplet size is one factor that an applicator can control in an attempt to lower the risk of drift. Small droplets are more sensitive to being blown off-target by wind than larger droplets. For example, a computer model, verified with wind tunnel testing, showed that when released 18 inches above a target in a 10-mph wind, a 100-μm droplet will travel more than 17 feet downwind. By comparison, a 200-μm droplet will travel less than 1 foot under the same conditions, and a 50-μm droplet will travel more than 50 feet downwind before evaporating completely and failing to reach the ground (Zhu et al. 1994).

Temperature and humidity primarily influence vapor drift. High temperatures and low humidity increase volatilization of pesticides into gases and thus the risk of vapor drift. Spray droplets begin evaporating as soon as they leave the nozzle, so these factors also can influence particle drift. In high temperatures and low humidity, droplets will evaporate quicker. As there size is reduced, they become more susceptible to being blown off-target by the wind. The influence of temperature and humidity is much greater on small droplets than large droplets. Using the previously mentioned model, a 70-μm spray droplet falling from 18 inches will be reduced to around 60 μm at a temperature of 50°F and to around 43 μm at a temperature of 68°F. By comparison, a 200-μm droplet will only be reduced to 199 μm at a temperature of 68°F. The same relationship can be seen with respect to humidity. Low humidity will reduce the size of small droplets more than larger droplets.

Low temperature and high humidity, conditions that reduce evaporation, can actually increase the distance extremely small droplets can move in the wind by prolonging the life

**Table 3.** ASAE S-572 droplet size spectrum categories recommended for various pesticide applications.

| Droplet spectrum (by ASAE S-572) | Contact insecticide and fungicide | Systemic insecticide and fungicide | Contact foliar herbicide | Systemic foliar herbicide | Soil-applied herbicide | Incorporated soil-applied herbicide |
|---|---|---|---|---|---|---|
| Very fine VF | | | | | | |
| Fine F | ✦ | | | | | |
| Medium M | ✦ | ✦ | ✦ | ✦ | | |
| Coarse C | | ✦ | | ✦ | ✦ | ✦ |
| Very coarse VC | | | | | ✦ | ✦ |
| Extremely coarse XC | | | | | | ✦ |

of the droplet before it evaporates. A 50-µm droplet, at 65°F and dropped from a height of 18 inches in a 10-mph wind, will travel 48 feet downwind before evaporating, never reaching the ground, at 20% relative humidity. This same droplet will travel 76 feet downwind and deposit on the ground in 100% relative humidity (Zhu et al. 1994).

## Coverage and Deposition

To understand how the size of the spray droplets affects coverage of the target, it is important to understand the relationship between droplet diameter, droplet volume, and the number of droplets. If the diameter of a droplet is doubled, the resulting droplet is 8 times greater in volume. This means eight 200-µm droplets contain the same volume of liquid as one 400-µm droplet. This is why smaller droplet sizes tend to give better coverage. With any given volume of liquid, there will be more droplets if you atomize the liquid into small droplets as opposed to large ones. More droplets means better coverage of the target. Droplets around 150 µm have been found to deposit more efficiently on leaves than larger droplets (Smith et al. 2000, Feng et al. 2003).

Reaching the target, however, is just as important as covering and depositing on it. The low mass of small droplets makes it more difficult for them to penetrate the canopy of target plants. Small droplets fall slowly and are more likely to be blown away or remain suspended in the air until they evaporate. If any of these situations occur, deposition on the target will be prevented and the efficacy of the application will be reduced. Larger droplets are better able to penetrate the canopy (Zhu et al. 2002, 2004) and have been shown to provide better absorption (Feng et al. 2003). The size of droplet best able to penetrate a canopy also depends on the density of the canopy, which is a function of the crop species and age.

Attempting to force small droplets into the canopy by using high pressure does not work. Using higher pressure to increase the initial droplet velocity can slightly decrease the distance 100 µm and larger spray droplets will drift, but it will have little or no effect on drift distance for droplets smaller than 100 µm (Zhu et al. 1994). Small droplets are not heavy enough to be forced into the canopy. The key is to create the droplet size spectrum required for the type of application to get a good balance of coverage, penetration, and deposition.

## Ground Application Equipment

There are several ways an applicator using ground equipment can control the size of spray droplets created during an application. One of the most important ways is by selecting and correctly using the proper nozzle. There are a variety of nozzle types available, and an applicator can match the droplet sizes created by a nozzle design to the type of pesticide being applied using the previously mentioned droplet spectrum categories.

The size of the nozzle orifice influences droplet size. In general, nozzles with large orifices produce larger spray droplets, whereas nozzles with smaller orifices produce smaller spray droplets. Also, as pressure is increased, smaller droplets are created. Using low pressures reduces the amount of small spray droplets. An applicator needs to use manufacturer's information to maintain an operating pressure that yields the necessary droplet spectrum. Spray rate controllers use pressure to adjust the nozzle flow rate during speed changes to maintain a constant gallons per acre rate. This change in pressure can have the unintended consequence of also changing the droplet size spectrum.

Extended range nozzles can be used at higher pressures to create finer sprays for insecticide and fungicide applications. Preorifice and turbulence chamber nozzles reduce the percentage of small spray droplets within the droplet spectrum and are popular nozzle type for making post emergent herbicide applications. Air-induction or venturi style nozzles are another type of nozzle designed to increase the droplet size, and they also are very popular for applying herbicides.

Lowering the boom height also will reduce the risk of drift during an application. The higher the boom, the greater the distance the spray droplets must travel to reach the target. This means they are more susceptible to movement by wind. Technology called pulse width modulation (PWM) allows for independent control of nozzle flow rate and pressure and can be used to control droplet size. Drift reduction additives are another tool that can be used by both ground and aerial applicators to reduce the formation of small droplets.

## Aerial Application Equipment

Nozzles are important for controlling droplet size during aerial applications as well. Aerial applicators have a variety of nozzle types to choose from. CP nozzles are commonly used by many applicators and have multiple orifices, allowing the applicator to quickly change nozzle flow rate. This style of nozzle also has deflectors that change the angle from which the spray sheet leaves the nozzle. CP-09 nozzle, for example, has a straight stream setting, and a 5° and 30° deflection setting. By changing the deflector angle, or nozzle orientation if using a flat fan nozzle, the droplet size spectrum can be altered. This occurs because of sheer on the spray as it enters the high speed air resulting from the aircraft's movement. As droplets enter this air, they can be shattered into smaller droplets. To reduce the formation of fine droplets, the deflector angle or nozzle orientation should be set so that the spray pattern is parallel to the air movement. By increasing the angle from this point, shear

on the droplets is greater, resulting in the creation of more small droplets. With flat fan nozzles, the narrower the fan angle the less shear on the droplets and the fewer small droplets created (Gardisser and Kulhman 1993).

A valuable tool that aerial applicators have to assist in setting up their aircraft is the Aerial Spray Nozzle Models developed by the USDA–ARS Aerial Application Technology research team at College Station, TX (USDA–ARS 2004). By entering the nozzle type, orifice size, nozzle or deflector angle, pressure, and air speed, the model calculates the VMD, percentage of volume contained in droplets smaller than 100 μm and 200 μm. This allows an aerial applicator to set up the aircraft to create the droplet spectrum required for job. The JARBA system is a boom that can be rotated in flight to change the angle of nozzle orientation, thus altering the droplet spectrum in flight.

Although keeping the boom as low as possible works well for ground applicators, flying too low can actually increase drift and reduce deposition for aerial applicators. An ideal height for aircraft to fly is often between 10 and 14 feet above the canopy. Any higher and the droplets are excessively exposed to wind. At lower heights, droplets can become trapped and carried off in air turbulence caused by the aircraft flying so close to the crop canopy. This increased turbulence reduces deposition and increases the risk of drift (Hoffman and Tom 2000). The booms on agricultural aircraft are usually mounted below and behind the trailing edge of the wing to keep the nozzles away from the turbulent air coming off the wing. In addition, nozzle drops are often used on the nozzles behind the propeller to further distance these nozzles from air turbulence caused by the movement of the propeller (Gardisser and Kulhman 1993).

## Conclusion

Droplet size plays an important role in pesticide applications, whether they are ground or aerial. The size of the droplets affects both the success of the treatment and the risk of drift. Future research will focus on further examining the relationships between droplet size, coverage, canopy penetration, deposition, and efficacy.

## References


Feng, P.C., T. Chiu, R.D. Sammons, and J.S. Ryerse. 2003. Droplet size affects glyphosate retention, absorption, and translocation in corn. Weed Science 51: 443–448.

Gardisser, D.R. and D.K. Kuhlman. 1993. Agricultural aircraft calibration and setup for spraying. University of Arkansas Extension Publication MP-348.

Hoffman, W.C. and H.H. Tom. 2000. Effects of lowering spray boom in flight on swath width and drift. Applied Engineering in Agriculture 16: 217–220.

Smith, D.B., S.D. Askew, W.H. Morris, D.R. Shaw, and M. Boyette. 2000. Droplet size and leaf morphology effects on pesticide spray deposition. Transactions of the ASAE 43: 255–259.

USDA–ARS. 2004. Aerial spray nozzle models. http://apmru.usda.gov/downloads/downloads.htm. Accessed October, 2004.

Zhu, H., D.L. Reichard, R.D. Fox, R.D. Brazee, and H.E. Ozkan. 1994. Simulation of drift of discrete sizes of water droplets from field sprayers. Transactions of the ASAE 37: 1401–1407.

Zhu, H., D.L. Rowland, J.W. Dorner, R.C. Derksen, and R.B. Sorensen. 2002. Influence of plant structure, orifice size, and nozzle inclination on spray penetration into peanut canopy. Transactions of the ASAE 45: 1295–1301.

Zhu, H., J.W. Dorner, D.L. Rowland, R.C. Derksen, and H.E. Ozkan. 2004. Spray penetration into peanut canopies with hydraulic nozzle tips. Biosystems Engineering 87: 275–283.

# Management of Soybean Foliar Diseases With Fungicides

*Donald Hershman*

## Historical Background

Historically, fungicide use on soybean has occurred mainly in the southern United States where disease pressure by foliar fungal pathogens tends to be consistently high each year. In Kentucky, few soybean fields have been treated with foliar fungicides since the early 1980s due to inconsistent yield results when fungicides are applied. This inconsistency has been shown to be due to highly variable disease pressure from year to year. Kentucky is a transition state, climactically, and is neither north nor south, but has characteristics of both regions.

In fact, few grain producers in Kentucky have ever applied foliar fungicides to soybean for foliar disease control. A larger number of seed producers have used foliar fungicides because seed quality problems associated with late-season infection by *Phomopsis* spp. tend to be more common than foliar, stem, and other pod diseases. In addition, economics associated with seed production tend to be more favorable for investing in fungicide applications.

## Current Situation

In 2002, Syngenta Crop Protection, Inc. began testing a combination of Quadris (azoxystrobin, a strobilurin fungicide), and Warrior (lambda-cyhalothrin, a pyrethroid insecticide), applied as a preventative spray at early- to mid-pod formation, in grower fields in Kentucky and southern Indiana. Results from 13 locations (nonreplicated paired strip-plots where an application of Quadris [6.2 fl oz/acre] + Warrior [2.56 fl oz/acre] were compared with a nontreated strip) indicated an average yield response of 6.8 bu/acre (range 1 to 14 bu/acre). No pest data were collected to indicate which, if any, pests were controlled to result in such dramatic yield increases. Nonetheless, these encouraging data prompted Syngenta to offer a "guarantee program" to selected growers in 2003. This program resulted in approximately 30,000 acres of soybean being treated with Quadris + Warrior in Kentucky during 2003. Concurrently, the University of Kentucky initiated studies in an attempt to verify 2002 yield results reported by Syngenta and to determine which, if any, pests the Quadris + Warrior treatment may be controlling. Studies in 2003 included two replicated small-plot tests, three large-scale replicated strip plots in grower fields, six paired strip-plot tests in grower fields, and a summary of yield results from 51 grower fields where Quadris + Warrior was applied.

## 2003 Results

Yield results from 2003 studies were similar to those reported from 2002. Across all studies and locations, the average yield increase was 4.7 bu/acre (range 0 to 14 bu/acre).

Where yield increases occurred in our 2003 tests, they were due to increased 500-seed weights and test weights; whereas the numbers of pods/plant and seed/pods were unaffected by Quadris + Warrior. In 11 tests where observations were made, defoliation was delayed by 4 to 5 days where Quadris was applied alone or in combination with Warrior. Warrior by itself did not impact defoliation. In nine of 11 tests, stem anthracnose, which was uniformly high in 2003, was reduced by 50 to 70% by any treatment involving Quadris. Conversely, pod anthracnose was variably controlled by the same treatments, and seed infection by *Phomopsis* spp. was unaffected by any treatment. No significant insect pests or foliar diseases developed in any test.

At first glace, it would seem that delayed defoliation and stem anthracnose control are at the root of yield increases in 2003. This theory falls apart, however, because none of the three locations where Quadris was applied alone produced a significant yield result. In fact, in tests where Quadris was compared with Quadris + Warrior, only the latter treatment produced a significant yield result. Both treatments, however, affected defoliation and stem anthracnose similarly. Warrior applied by itself was not different from the check in any test. Because the 2003 Syngenta guarantee program involved the application of both Quadris and Warrior as a tank mix, there are limited data to indicate how Quadris performs in the absence of Warrior. In

addition, I am not aware of any pest data taken in any of the 51 strip tests for which yield data were summarized. Consequently, by the end of the 2003 season, we were still no closer to knowing what a single application of Quadris + Warrior might be doing to result in what seemed to be real and significant yield increases.

Variable yield results in 2002 and 2003 may be due to a variety of different and overlapping factors. Certainly, variation in pest pressure (both obvious and hidden) from field to field is a likely factor. In addition, variable yield response may be related to differences in cultivar maturity, susceptibility to pests, and planting dates. Preliminary data from 2003 suggest that very late-planted crops (late June to early July) and late-maturing cultivars (MG Vs in Kentucky) may have a reduced response potential to the Quadris + Warrior treatment compared with early planted, early maturing crops. Variable yield response also may be due to variable application methods and equipment. For example, application research being conducted in Kentucky during 2004 has shown how difficult it is to get pesticide penetration into a full-size soybean canopy. With this awareness, it is very likely that some producers do a better job than others at applying foliar treatments. In addition, no matter how conscientious the farmer, current spray technology is suspect for achieving good pesticide penetration into a soybean canopy. This technology shortfall is confounded because farmers frequently cut spray volume considerably as a means of reducing time spent refilling the spray tank.

Differences in yield response to Quadris + Warrior also may be related to differences in canopy size at the time treatments were applied. For example, in Kentucky a typical MG 3 soybean cultivar will be about knee-high by the time it reaches the R4 (mid-pod stage) stage. In contrast, most MG 5 cultivars will be nearly twice as tall at the same growth stage. Obviously, achieving good pesticide penetration will be easier in a smaller soybean canopy. Timing of application also may account for variable yield results. For example, the results from a timing of application study in 2003 indicated that only an application at the R4, but not at R3 (beginning pod) or R5 (full pod), resulted in a significantly higher yields compared with the check. Finally, row spacing, which dramatically impacts canopy density, may be an another reason why some fields responded better than others to the application of Quadris and Warrior in 2002 and 2003; both 15-in. and 30-in. rows are common in Kentucky.

**Note:** For more details on what was done in 2003 and the results, please review the related report in this proceedings written by Douglas. W. Johnson and myself entitled, Where is the IPM in Treating Soybean with a Fungicide/Insecticide Combination in the Absence of Pests?

## 2004 Studies and Preliminary Results

Studies in 2004 were geared to confirm 2003 results and dig deeper into possible factors that may be impacting yields when Quadris + Warrior is applied. Studies were funded by the Kentucky Soybean Promotion Board. A planting date × cultivar maturity study was initiated, as was a trial looking at the efficacy of various fungicide active ingredients, with and without insecticide. A timing study initiated in 2003, and another 2003 study where various fungicide and insecticides were applied at the R4 stage, also were repeated in 2004.

Observations from the 2004 tests indicate that defoliation differences between treated and nontreated soybean were greatly reduced compared with tests in 2003. I had great difficulty discerning visual differences for any treatment in any test in 2004. Disease and insect levels for 2004 were very similar to what was observed in 2003. For example, stem anthracnose was the only disease that developed to significant levels; no single foliar disease was extensive in any test and insect populations were generally low. I did note that a complex comprised of background levels of several foliar fungal diseases (brown spot, frogeye leaf spot, and Cercospora leaf blight) were consistently reduced in the mid-canopy and upper canopy in all plots where Quadris or Quadris + Warrior were applied. However, the overall levels of fungal diseases present did not appear to be yield-limiting. It is possible that background levels of foliar diseases may have a more significant impact on yield than I realize.

Yield results at this time are incomplete. Preliminary results from the fungicide timing study indicate that only the Quadris + Warrior treatment applied at R5 may have resulted in a significant yield increase (8.5 bu/acre). Similar applications of Quadris or Warrior applied at R5, and all treatments applied at R3 or R4 do not seem to have yielded differently from the check. As in 2003, the disease control differences between the Quadris and Quadris + Warrior treatments applied at R3, R4, and R5 stages were very similar. Yet, only the R5 application of Quadris + Warrior seems to have produced a positive yield response. In another test, there does not seem to be a significant yield difference associated with application of either Quadris or Quadris + Warrior, but both treatments reduced stem anthracnose and lowered the foliar disease complex mentioned above. Hopefully, additional yield and pest data from the 2004 tests will shed more light on the current situation.

## Present State of Knowledge?

Yield increase data reported by Syngenta from 2002, and more or less corroborated by us and others in Kentucky during 2003, indicate that yields are increased more times

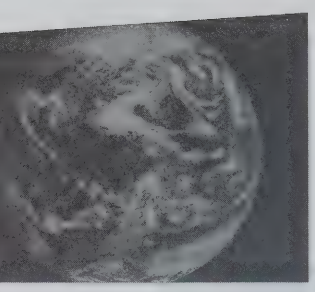
than not when Quadris (6.2 fl oz/acre) + Warrior (2.56 fl oz/acre) is applied to soybean during the early to late-pod stages. In many cases, yield increases are substantial; in other instances, there are no yield increases. Partial, preliminary data from 2004 are generally not favoring a yield response to the Quadris + Warrior treatment. However, a great deal more data, including on-farm data, are still to be evaluated from 2004.

As of this writing, we do not have a complete understanding of what the Quadris + Warrior treatment may be doing when applied to soybean that could result in such a large yield increase in so many fields. The answer is apparently not obvious and does not seem to follow pest control and yield patterns that we have come to expect. However, just because we do not understand something does not mean it is not real. It may simply means we have more to learn. On the other hand, everything could fall apart based on 2004 data, and we all need to be open to that possibility. Therefore, we are in a conundrum. We cannot just ignore the Quadris + Warrior treatment simply because we may not understand what it is doing or because it goes against established integrated pest management principles. On the other hand, we cannot whole-heartedly recommend the treatment until we determine the situations for which the treatment provides consistent results. Until we get this situation worked out, soybean farmers are likely to continue to "test" the treatment and will accept or reject it based on how it performs economically on their farms.

## Link to Asian Soybean Rust

Asian soybean rust (ASR) is coming to the continental United States; the only question is when. For the foreseeable future, once ASR arrives, the only practical means of control will be with foliar fungicides. The Environmental Protection Agency has already granted emergency (section 18) labels for several fungicides to many soybean-producing states in anticipation of the arrival of ASR. With this in mind, the interest in applying fungicides to soybean—before ASR arrives—is opportunistic because it will facilitate moving growers into ASR management programs. For example, by the time ASR arrives, many soybean farmers will have had significant experience applying fungicides to soybean late in the season. Late-season application includes many logistical considerations, including getting farmers used to looking in fields later in the season than they are used to, encouraging grower familiarity with common foliar diseases, and prompting growers to acquire sprayers and/or develop new relationships with commercial pesticide applicators. In addition, farmers will have more experience in achieving the best possible canopy coverage when applying fungicides to soybean late in the season. Keep in mind that spraying a full-size soybean canopy to achieve ASR control will be very different than spraying soybean 30 days after planting for weed control. Thus, the extra experience farmers are able to glean from applying fungicides now will be a great help to them later once the disease "stakes" are higher.

# Do Foliar Fungicides Have a Place in Corn Production?



*Gregory Shaner*

Corn is subject to several foliar diseases. Some of these are only occasional problems; others have been widespread and severe on some hybrids in recent years. Genetic resistance has long been the major line of defense against these diseases. However, some hybrids are susceptible. For these, a fungicide may be used to protect the crop.

What diseases are amenable to control with foliar fungicides? Gray leaf spot, northern corn leaf blight, and common rust are the main concerns. Gray leaf spot became a problem during the 1990s and continues to be a threat. Northern corn leaf blight has reemerged as a problem on some hybrids. Common rust is not usually a problem on hybrid field corn, but in some years it comes in early enough to cause damage. Stalk rots may be indirectly influenced by use of a fungicide on corn—a plant with healthy leaves is less vulnerable to premature stalk senescence and rot.

Before discussing how fungicides protect corn from disease, it is useful to consider how leaf diseases damage corn. The corn plant is an efficient photosynthetic factory. Leaves use the energy provided by sunlight, along with carbon dioxide in the atmosphere and water taken from the soil, to manufacture carbohydrates. These form the building blocks for many other constituents of the corn plant needed for growth, and development of grain. When leaf tissue is prematurely killed, the efficiency of this photosynthetic factory is compromised, which reduces yield and grain quality.

The diseases of corn that are targets for foliar fungicides are polycyclic diseases. This phrase describes diseases in which the number of infections increases during the growing season as a result of inoculum produced on diseased plants. For these diseases, a single infection never kills the plant, or even destroys a significant amount of leaf tissue. But as the number of infections increases, they destroy a lot of leaf area. Consider gray leaf spot, caused by the fungus *Cercosporella zeae-maydis*. When a spore of this fungus lands on a leaf, it germinates when temperature is suitable (75–85°F) and moisture is adequate (≥95% RH for at least 12 h). The fungus germ tube grows over the leaf for a time and then enters the leaf through a stomate. After infection, the fungus grows inside the leaf without causing any external symptoms. This time is the incubation period, and for gray leaf spot it may be longer than 2 weeks. For some other leaf blights, the incubation is shorter. Eventually, a visible disease lesion develops at the site of infection. Once a lesion develops, the fungus produces spores in this tissue. Spores are the means by which fungi reproduce. Each lesion may produce hundreds or thousands of microscopic spores. Wind or rain splash disperse these spores. Spores that land on healthy leaf tissue can infect and produce more lesions, which produce more spores. With each cycle of infection, more and more leaf tissue is destroyed. Many infection cycles can occur during the growing season.

Several fungicides are labeled for foliar application on corn. Products labeled for field corn include propiconazole, azoxystrobin, and trifloxystrobin. Some of these are sold by more than one company, under different brand names. Labels for most of these fungicides state that the first application should be made at disease onset, when most plants are just starting to show disease symptoms. Lesions typically occur first on lower leaves, sometimes before corn has tasseled. Fungicide should be applied as soon as disease occurs because these products act mainly as protectants. Many modern fungicides are absorbed by the plant, but they have limited ability to eradicate established infections. This point brings us back to the incubation period. When we assess severity of disease based on the number of visible lesions on leaves, we are seeing only infections that have passed through the incubation period. If a grower waits until there is enough visible infection to reduce yield, there will likely be too much additional, but not yet visible, infection for a fungicide to provide sufficient protection. Waiting too long to begin treatment will result in unsatisfactory control.

If a fungicide is first applied at disease onset, which may be in mid- to late July, will additional applications be necessary? If weather remains favorable for disease and the hybrid is susceptible, a second treatment, about 2 weeks after the first, may be necessary. Labels for specific products

discuss the circumstances for a second application, and indicate preharvest intervals for the last application.

Most of our research on control of corn diseases with foliar fungicides has been with seed corn. These results can be extrapolated to hybrid corn with two important provisos. Many inbreds are more susceptible than hybrids to disease. Also, the detasseling operation removes most of the leaves above the ear, so that grain development depends on the photosynthetic capacity of leaves that would constitute the lower half of the canopy on hybrid corn. Because most foliar diseases of corn progress from lower to upper leaves, these lower leaves tend to have more infection than would upper leaves, were they left on the plant. Therefore, yield responses to fungicides in seed corn are likely to be greater than would be seen in most corn hybrids.

We have conducted experiments in commercial seed production fields for the past 6 years. Some products were tested in all years; others were tested in only some years. For most products, we compared a single application at disease onset with a double application, the first at disease onset and the second about 2 weeks later, at silking. We assessed disease severity on the ear leaf as percentage of leaf area showing symptoms. The experiments included products already labeled for field corn, products labeled only for other crops, and experimental products not yet labeled at all. Results reported here are for products labeled or presumably soon to be labeled for field corn.

In direct comparisons of Quadris (azoxystrobin) and Tilt (propiconazole), Quadris provided better disease control than Tilt averaged over all tests (Table 1). The difference between the two products was more pronounced when there was only one application. The yield response was more striking; Quadris increased yield much more than Tilt. Two applications of Quadris increased yield considerably more than did a single application of Quadris. The multiple-year averages presented in Table 1 conceal the year-to-year variation in results. In some years, differences between products or application timings were not large; in other years they were substantial.

Quadris, Headline (pyraclostrobin—not yet labeled for corn as of October 2004), and Stratego (a mixture of azoxystrobin and propiconazole) provided similar disease control and equal increases in yield, when applied only at disease onset (Table 2).

Foliar fungicides have not been used much on field corn for two reasons. Many corn hybrids have reasonably good resistance to foliar diseases. The low per acre return on corn, compared with fruits and vegetables, on which fungicides are commonly used, makes use of fungicides risky unless there is an adequate return in improved yield and grain quality. Because little foliar fungicide is used on hybrid corn, there has not been much research in this area. There has been research on use of fungicides on inbreds used for seed production, but extrapolation of these results to hybrid corn must be done carefully, for reasons stated above. The first line of defense against gray leaf spot, northern corn leaf blight, common rust, and other foliar diseases is to choose a hybrid with adequate resistance to these diseases. Corn grown in the vicinity of residue from the previous year's corn crop is at greater risk for many of these diseases than corn grown where there is little residue. Wherever conservation tillage is practiced, disease resistance should be an important consideration in choosing hybrids.

If hybrids with adequate resistance cannot be grown, a foliar fungicide may protect the crop. If a fungicide is used, scouting for the first signs of disease is important. So is accurate diagnosis of diseases that are found. In general, frequent rains, heavy dews, and moderate temperatures (good corn growing weather) favor disease. Corn yields for Illinois and Indiana were high in 2004, but some hybrids were severely damaged by disease. Even though growers may be satisfied with the yields they got, if these susceptible hybrids had been treated with a fungicide, the yields may have been impressively greater.

**Table 1.** Comparison of disease control provided by Quadris or Tilt.

| Treatment | Disease control (%) | Yield increase (bu/acre) |
|---|---|---|
| Quadris 9.2 fl oz/acre, DO | 71 | 23.2 |
| Quadris 9.2 fl oz/acre, DO + R1 | 68 | 14.4 |
| Tilt 4 fl oz/acre, DO | 21 | 8.9 |
| Tilt 4 fl oz/acre, DO + R1 | 52 | 7.3 |

DO, treatment at disease onset.
R1, treatment at beginning silk.
Data from 1999, 2000, 2002, 2003, and 2004.

**Table 2.** Comparison of disease control provided by Quadris, Headline, or Stratego.

| Treatment | Disease control (%) | Yield increase (bu/acre) |
|---|---|---|
| Quadris 9.2 fl oz/acre, DO | 37 | 4.2 |
| Headline 9 fl oz/acre, DO | 43 | 7.8 |
| Stratego 10 fl oz/acre, DO | 37 | 3.9 |

DO, treatment at disease onset.
Differences in yield increase are not statistically significant.
Data from 2001, 2002, and 2004.

# Management of Wheat Diseases With Fungicides

*Donald E. Hershman*

## Historical Use of Foliar Fungicide on Wheat

When I first arrived on the wheat disease "scene" in 1984, there were very few foliar fungicides available for wheat producers to use and still fewer who were willing to apply them. Back then, most producers in Kentucky (and probably Illinois, too) did not think of wheat as a primary crop—one that was worthy of much time or expenditure. Things changed rapidly in the early 1990s when many wheat producers began to discover that they could produce fairly high-yielding wheat, at least by U.S. standards.

One aspect of producing wheat that has changed radically is the use of foliar fungicides. In 1984, perhaps 10% of the wheat producers in Kentucky were willing to apply foliar fungicides, and about 1% actually did. At that time, the main product in use was mancozeb (e.g, Dithane M-45) because it was cheap and provided fair, albeit short-term, disease control when properly applied. Triadimefon (i.e., Bayleton, Bayer) was also available, but few farmers used it because of its relative high cost. In late 1987, propiconazole (Tilt, Syngenta) became available. Tilt, a partially systemic triazole with a degree after-infection activity, was relatively inexpensive, was easy to handle due to its oil-based formulation, and was very effective against several common foliar and head diseases.

One major limitation with the Tilt label was (and still is) that it could not be applied after flag leaf extension. In Kentucky and most states where soft red winter wheat is grown, the optimal time for fungicide application is at heading or later, 7 to 14 days after flag leaf emergence. I have seen almost no data for soft red winter wheat over 20 years to support earlier applications of Tilt (or other foliar fungicides for that matter) unless early powdery mildew is a significant problem. This presented growers with a problem: to use Tilt according to label directions and get no or poor disease control, or to apply Tilt off-label and get very good to excellent disease control (assuming, of course, that field disease history, current disease levels, and current/forecasted weather all indicated that a fungicide application was needed!). In any event, the labeling of Tilt ushered in a new era in fungicide use in many states, including Kentucky. For example by 1990, approximately 20% of all wheat acres were sprayed with fungicides, with the lions share going to Tilt. By 2000, that number was 30-40%, depending on the year.

After the labeling of Tilt in 1987, there was a 12-year drought in labeling new wheat foliar fungicides. Then in 1999, azoxystrobin (Quadris, Syngenta) received a label. Quadris represented a new class of fungicides called strobilurins. Quadris had the benefit, too, that producers could apply the product up to the beginning of crop flowering. Still, little Quadris was used due to its very high cost compared with Tilt. Since then, several new fungicides have received labels, including trifloxystrobin + propiconazole (2001, Stratego, Bayer), another propiconazole product (2001, PropiMax, Dow), pyraclostrobin (2003, Headline, BASF), and azoxystrobin + propiconazole (2004, Quilt, Syngenta). The wheat fungicide "toolbox" is now nearly full. Several other products, such as tebuconazole (Folicur, Bayer) await labeling depending on the outcome of EPA's review of the triazole class of fungicides.

## Comparative Efficacy of Modern Wheat Foliar Fungicides

Table 1, developed by the North Central Regional Committee on Management of Small Grain Diseases (NCR 184) shows accepted relative fungicide efficacy for modern wheat fungicides labeled in the United States.

As you can see from Table 1, there is not a great deal of difference in potential disease control activity between any of the modern fungicides, except for powdery mildew control, which is rather poor for most products containing strobilurin chemistry.

## Fungicide "Hog Heaven"?

Even though it looks like Kentucky and Illinois wheat producers are in fungicide "hog heaven," this is not actually

**Table 1.** NCR-184 management of small grain diseases, fungicide efficacy for control of wheat diseases.

| Product | Fungicide(s) | Rate/acre | Powdery mildew | Stagonospora leaf/glume blotch | Septoria leaf blotch | Tan spot | Stripe rust | Leaf rust | Head scab |
|---|---|---|---|---|---|---|---|---|---|
| Tilt 3.6 EC | Propiconazole 41.8% | 4 fl oz | +++* | +++ | +++ | +++ | +++ | +++ | + |
| PropiMax 3.6 EC | Propiconazole 41.8% | 4 fl oz | +++ | +++ | +++ | +++ | +++ | +++ | + |
| Quadris 2.08 SC | Azoxystrobin 22.9% | 6.2 (to 10.8) fl oz | +(+)** | +++ | +++ | ++++ | ++++ | ++++ | |
| Quilt 200SC | Azoxystrobin 7.0%<br>Propiconazole 11.7% | 14 fl oz | +++ | +++ | +++ | +++ | +++ | +++ | |
| Stratego 250 EC | Propiconazole 11.4%<br>Trifloxystrobin 11.4% | 10.0 fl oz | ++ | +++ | +++ | +++ | +++ | ++ | |
| Headline 2.09 EC | Pyraclostrobin 23.6% | 6.0 (to 9.0) fl oz | ++ | +++ | +++ | ++++ | ++++ | ++++ | |
| Folicur 3.6 EC*** | Tebuconazole 38.7% | 4.0 fl oz | ++ | +++ | +++ | +++ | ++++ | ++++ | ++ |

* The greater the number of + signs, the greater the relative efficacy.

** + indicates greater efficacy at higher application rates.

*** Folicur does not have a federal label, but may have Section 18 emergency registration in some states.

**NOTE:** Efficacy ratings for each fungicide listed in the table were determined by field testing the materials over multiple years and locations by the members of the committee. **Efficacy is based on proper application timing to achieve optimum effectiveness of the fungicide as determined by labeled instructions and overall level of disease in the field at the time of application.** Differences in efficacy among fungicide products were determined by direct comparisons among products in field tests and are based on a single application of the labeled rate as listed in the table. This information is provided only as a guide. It is the responsibility of the pesticide applicator by law to read and follow all current label directions. No endorsement is intended for products listed, nor is criticism meant for products not listed. Members of NCR-184 assume no liability resulting from the use of these products.

the case. For example, fungicides containing propiconazole still cannot be legally applied in Illinois and Kentucky once crop flag leaf extension has occurred. In Kentucky, state law has kept fungicide manufacturers from getting section 24c labels for those products. In addition, Quadris continues to be too expensive for most producers to consider using. Headline is about as inexpensive as Tilt, can be applied up to the start of crop flowering (Feeke's stage 10.5) and has equal or slightly better disease control activity than Tilt, except for powdery mildew, which is a weakness for Headline. However, when Headline is applied after head emergence (a popular time of application), slightly **increased** levels of deoxynivalenol (DON) in harvested grain often results when Fusarium head blight (FHB) is a problem. Other strobilurin-based fungicides have the same problem. Increased DON can result in increased dockage at the time of sale, or even rejection of grain at elevator.

Having looked over a great deal data from various parts of the world, including the United States, it is clear to me that applying a strobilurin-based fungicide after crop heading increases DON levels about one-half the time. Table 2, presents 2004 data from Kentucky and Illinois and provides evidence to support this statement.

As can be seen above, mean DON levels across the eight tests were numerically higher (statistics not available at this time) compared with the check in 10 (bolded means) of 12 instances. In contrast, DON levels were not increased in any of the eight tests when the triazole, Folicur, was applied.

The possibility of enhancing DON by applying a strobilurin fungicide hangs over the head of producers from the time of product application until the sale of grain. Unfortunately, FHB and DON cannot yet be accurately predicted. Thus, a producer really has no way of knowing whether and to what extent FHB and DON will develop. This situation makes planning very difficult, because risk cannot be adequately addressed. Having said all this, DON is not an issue in many years, so applying a strobilurin fungicide in off-DON years is not a problem. But at least for the foreseeable future, until FHB/DON forecasting can be done accurately, enhanced DON seems to be a risk when applying strobilurin-based fungicides. One piece of the puzzle that has yet to be determined is whether appli-

**Table 2.** DON results from eight fungicide tests conducted in Illinois and Kentucky.

| Test location and no. | DON (ppm) Check | Folicur | Quadris | Quilt | Stratego | Headline |
|---|---|---|---|---|---|---|
| KY 1 | 4.5 | 4.2 | . | 5 | . | . |
| KY 2 | 0.8 | 0.6 | . | 1 | 1.1 | 1.4 |
| KY 3* | 3.53 | 1.67 | . | 3.33 | . | 6.1 |
| KY 4* | 9.6 | 7.38 | . | 5.93 | . | 11.26 |
| IL 1* | 0.42 | . | . | 1.12 | . | 1.55 |
| IL 2** | 2.4 | 1.6 | . | . | . | . |
| IL 3** | 10.3 | 9.3 | 11.3 | . | . | . |
| IL 4** | 0.7 | 0.5 | 1.2 | . | . | |

* OptiCrop.
** University of Illinois.

cations of strobilurin-based fungicide prior to full head emergence, say at the split boot stage, enhance DON.

## Folicur Section 18 for Fusarium Head Blight and DON Suppression

One turn of events for both Illinois and Kentucky wheat producers in 2004 was the availability of Folicur, via emergency (section 18) labels, for suppression of FHB and DON. Due to the lateness of the approval date, not a great deal of Folicur was used in Kentucky in 2004. For example, we estimate that about 17,000 out of a possible 425,000 acres (4%) was sprayed with Folicur in Kentucky during 2004. My observations and data indicate that FHB and DON suppression were about what we expected. Table 3 summarizes partial, preliminary results of 11 winter wheat tests, as part of the 2004 U.S. Wheat and Barley Scab Initiative Uniform Fungicide Test.

In summary, Folicur suppressed both FHB and DON, but bona fide control (i.e., >90%) was not achieved. Going into the season, all the winter wheat data I was able to review suggested that we could expect Folicur to provide about 30–40% FHB suppression, and about 20–30% DON suppression, depending on the location. Based on what I saw in 2004, those numbers were right on target. It is my understanding that most, but not all, of the wheat producers who used Folicur in Kentucky were pleased with the results. Grain millers also seem to be pleased with the result of the Folicur section 18. Thus, our plan is to pursue another Folicur section 18 for 2005.

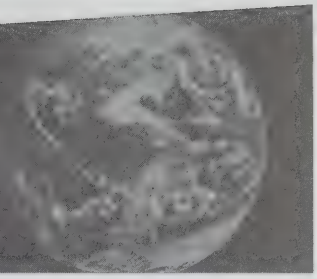
One thing that may stand in our way for 2005 is the tact EPA takes with other wheat fungicides. In 2004, EPA indicated that we would have to provide substantially more evidence in 2005 that 1) Tilt is ineffective and 2) fungicides containing strobilurin chemistry do have an increased risk of increasing DON accumulation in grain. We would not have much difficulty with point 2. However, it may be more difficult to convince EPA that Tilt does not work. It does to a limited extent, just not usually as well as Folicur. It will be interesting to see how it all works out in 2005.

**Table 3.** Partial, preliminary results from 11 fungicide tests conducted in Arkansas, Illinois, Missouri, Montana, and Ohio in 2004.

| Treatment/rate/A | Fusarium Head Blight % Incidence | % Severity | % Index | % FDK* | DON ppm |
|---|---|---|---|---|---|
| Nontreated | 52.3 | 37.6 | 19.6 | 20.1 | 4.8 |
| Folicur 4 fl oz | 47.1 | 29.9 | 15.4 | 13.6 | 4.1 |
| Tilt 4 fl oz | 45.9 | 30.2 | 15.3 | 13.7 | 4.8 |

*Fusarium.damaged kernels.

# *Delivering on the Biotech Promise Today and the Not so Distant Future*



*Tom West*

# Future of Insect Resistance Management: Balancing Ecology, Evolution, and Economics to Determine Best Management Practices

*Charles A. Guse, David W. Onstad, and David W. Crowder*

In the past decade, there have been major changes in our concept of how to manage the insects that attack crops. No system illustrates this better than our experiences with the western corn rootworm. In many areas of Illinois, growers were able to control rootworms with a simple 2-year crop rotation. Insecticides were only necessary in continuous corn. Recently, both western and northern corn rootworm populations have independently evolved behaviors that circumvent 2-year rotations. Consequently, insecticides are now used on first-year cornfields over a large part of the Midwest.

Inexpensive cultural control strategies that seemed reliable have failed, in part, because we did not understand the system. If we hope to have sustainable pest control, new tools must be implemented based on managing a large landscape, with a long-term perspective and an ecologically sound understanding of the system. Gaining this kind of knowledge requires years of very expensive experimentation. Mathematical simulation is used to summarize our understanding of the system and reproduce the biological interactions as a computer program. Equations are developed to describe the behavior and genetic characteristics of both the insects and crops. Simulating the yearly cycles of planting and insect behavior permits us to examine how the system behaves in a large landscape, over a long period. By changing control strategies in the simulation, we conduct experiments to see how insect populations are affected.

Our objective has been to develop a comprehensive understanding of how rootworms interact with corn. Early models helped us examine the scenarios that allowed rootworms to develop rotation resistance. We concluded that the 2-year rotation strategy was used too intensively over large portions of the landscape. Eggs laid in corn resulted in larvae that died in soybean fields the next year, but females that laid eggs in soybean had offspring that survived on corn. A computer program is not necessary to come to this conclusion. But, the model suggests that if more continuous corn had been planted, this problem might have been prevented. More importantly, we could determine the proportion of continuous corn necessary to prevent resistance. Hindsight is always 20/20, but we should try to learn the most from our failures.

Other models were developed to examine the various weather factors that contribute to the dispersal of the rotation-resistant variant across the Midwest. These models demonstrated how wind and storm systems were restricting dispersal to the west and south. Combining the ideas of storm dispersal with the concepts from the model of how rotation resistance had developed, we were able to explain how the allele frequencies of rotation resistance were being reduced toward the north and east because of cropping practices and landscape variability.

The most recent tool for rootworm control is transgenic insecticidal corn expressing the Cry 3Bb protein. Growers, industry, and the government share a common interest in keeping these products effective, safe, and reliable for many years. In anticipation of the release of these products, we modeled how rootworms might develop resistance to the toxin in different landscape management scenarios. Our models were part of the registration process for these products last spring.

The most recent models consider rotation resistance and transgenic resistance simultaneously. Perhaps more importantly, these models include grower economics. Management options are presented that incorporate insect behavior and resistance evolution while maximizing grower profits and protecting the longevity of transgenic tools. We also describe some of the ongoing modeling efforts and how these may affect growers.

# Glyphosate-Resistant Weeds in Illinois: Way Down the Road or Right Around the Corner?

*Patrick J. Tranel*

Weed management took a giant leap forward in 1996, with the commercialization of glyphosate-resistant soybean. This technology enabled the use of glyphosate—an effective, easy-to-use, broad-spectrum herbicide—as "the" tool for weed control in soybean. With glyphosate-resistant corn now also available, overreliance on glyphosate for weed control is a concern. Can farmers in Illinois count on glyphosate alone to provide satisfactory weed control into the foreseeable future? Or will herbicide resistance once again rear its ugly head, and take us back to the days when choosing a herbicide program requires more than just picking your favorite flavor of glyphosate?

Herbicide resistance occurs through natural selection or "survival of the fittest." By allowing rare, resistant individuals to survive and pass on resistance genes to their offspring, herbicides "select" for resistant biotypes. Over time, repeated applications of a particular herbicide will increase the frequency of resistant biotypes, to the point where the population as a whole becomes resistant. The time it takes for this to occur is dependent on essentially two factors: the initial frequency of the rare, resistant individuals, and the extent of the selection pressure (i.e., how often a particular herbicide is used).

With glyphosate, we know from previous experience and research that the initial frequency of rare, resistant individuals is much lower than what is observed for most other herbicides (Bradshaw et al. 1997). This suggests that resistance to glyphosate, compared with other herbicides, will occur slowly and infrequently. However, we also know that glyphosate has an unprecedented market share and therefore we are witnessing an unprecedented degree of selection pressure for resistance to a given herbicide. We also know that weed resistance to glyphosate, although rare, does exist (Table 1). Thus, if the current situation of widespread, heavy selection pressure for glyphosate resistance continues, it is really just a matter of when, not if, glyphosate-resistant weed populations will exist in Illinois.

## Predicting the Occurrence of Resistant Weed Populations

Mathematical models can be used to estimate how long it takes for a population to evolve herbicide resistance. The models must take into account various assumptions (e.g., in regard to soil seed bank dynamics, per-plant reproductive output, genetic nature of resistance) and therefore are not completely reliable. Nevertheless, such models are illustrative of several points. For example, if the initial frequency of rare, resistant individuals is one in a million (which is considered realistic for resistance to ALS-inhibiting herbicides), modeling predicts that it would take about 5 years of repeated herbicide use to result in a resistant population (Figure 1). In contrast, if the initial frequency of rare, resistant individuals is much lower (e.g., one in a billion, which might be realistic for resistance to glyphosate), then it would take close to 10 years of repeated herbicide use to produce a resistant population.

How many years has selection with glyphosate been occurring in Illinois fields? Well, before glyphosate-resistant crops, glyphosate was still commonly used, but primarily for preplant (burndown) weed control. Such use resulted in limited selection of many of our problematic summer annual weeds (e.g., waterhemp and common lambsquarters) for glyphosate resistance because most individuals of these species germinate subsequent to preplant applications. Thus, for many of our summer annual weeds, selection for glyphosate resistance has occurred 9 years at most (1996–2004). Furthermore, because most soybean fields are rotated with corn and because glyphosate-resistant corn has not yet been widely adopted in Illinois, many of our summer annual weed populations have experienced only about 5 years of selection for glyphosate resistance.

Certainly, the situation is not this simple, as we do not have isolated weed populations in Illinois. Gene flow (either by pollen or seed) among populations complicates the scenario. Multiple applications of glyphosate in a single year also can speed up the evolution of glyphosate resistance.

Nevertheless, if we consider that most summer annual weed populations in Illinois have experienced only about 5 years of selection by glyphosate, together with the models shown in Figure 1, we come to two conclusions. One, it is not surprising that we have not yet seen major problems with glyphosate-resistant weeds in Illinois. Two, we should expect to see glyphosate-resistant summer annual weed populations within the next 5 years.

## Current Status of Glyphosate Resistance

There are at least six weed species with confirmed glyphosate resistance (Table 1). In most of these cases, glyphosate resistance did not occur as a result of selection by glyphosate in glyphosate-resistant crops. Rather, resistance occurred typically after several years of very intensive selection by glyphosate in orchards (Heap 2004). Horseweed is the first weed to have evolved glyphosate resistance in conjunction with glyphosate-resistant crop. This weed grows both as a summer annual and a winter annual and thus experiences selection for glyphosate resistance by both in-crop and preplant glyphosate applications. That it had been experiencing selection by preplant glyphosate before the commercialization of glyphosate-resistant soybean is one explanation why it was the first weed to evolve glyphosate resistance in conjunction with glyphosate-resistant crops. Although glyphosate-resistant populations of horseweed have not yet been confirmed in Illinois, they probably already exist. First reported in Delaware in 2000, glyphosate-resistant horseweed populations are now common in Ohio and Indiana, and resistant populations also have been reported in Iowa.

It is anybody's guess as to what species will be the first in Illinois to evolve glyphosate resistance. My guesses are listed in Table 2. Waterhemp is of particular concern, because of its prior history of successful and rapid evolution of resistances to various herbicides. Although some scientists have claimed to identify glyphosate-resistant waterhemp populations, clear genetic inheritance of glyphosate resistance has not yet been demonstrated in these populations.

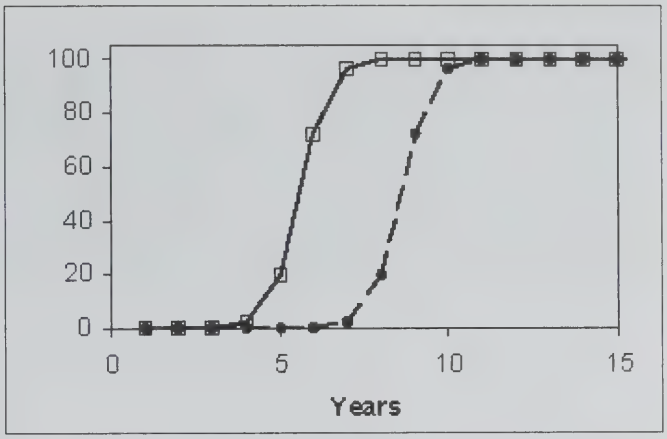



**Figure 1.** Models for the evolution of a herbicide-resistant weed population given two different initial frequencies of rare, resistant individuals (one in a million = $10^{-6}$; one in a billion = $10^{-9}$).

Waterhemp's response to glyphosate may more accurately be described as tolerance rather than resistance. This species is highly variable in morphology, growth form, pigmentation, and other traits. It also exhibits high variability in response to glyphosate. This variability probably existed before glyphosate selection; hence, the word "tolerance" rather than "resistance" to describe waterhemp's response to glyphosate. Nevertheless, continued selection by glyphosate may lead to an increased frequency of the least glyphosate-sensitive individuals of the species, making an already bad problem (variable glyphosate responses in waterhemp) even worse.

The glyphosate response situation with common lambsquarters may be similar to that of waterhemp. Common lambsquarters has a natural, low-level tolerance to glyphosate that could be made worse via overreliance on glyphosate. Both ragweed species found in Illinois (common ragweed and giant ragweed) are highly variable species that undergo substantial outcrossing. Consequently, these two species are also concerns in regard to glyphosate resistance.

**Table 1.** Weeds confirmed resistant to glyphosate (data from Heap 2004).

| Species | Year First Identified | Locations of Resistant Biotype |
|---|---|---|
| Rigid ryegrass (*Lolium rigidum*) | 1996 | Australia, United States, South Africa |
| Goosegrass (*Eleusine indica*) | 1997 | Malaysia |
| Horseweed/marestail (*Conyza canadensis*) | 2000 | United States |
| Italian ryegrass (*Lolium multiflorum*) | 2001 | Chile, Brazil |
| Hairy fleabane (*Conyza bonariensis*) | 2003 | South Africa, Spain |
| Buckhorn plantain (*Plantago lanceolata*) | 2003 | South Africa |

**Table 2.** Potential glyphosate-resistant weeds to "be on the lookout for" in Illinois.

| Species | Status |
|---|---|
| Horseweed/marestail (*Conyza canadensis*) | Glyphosate-resistant populations present in neighboring states; probably already present in Illinois |
| Waterhemp (*Amaranthus tuberculatus*) | Populations highly variable in response to glyphosate; genetic control (i.e., inheritance) of this variability is not clear |
| Common lambsquarters (*Chenopodium album*) | Like waterhemp, may have some tolerance to glyphosate; a resistant population was preliminarily reported in Virginia[1] |
| Common ragweed (*Ambrosia artemisiifolia*) | Resistant populations preliminarily reported in Missouri[2] and Arkansas[3] |
| Giant ragweed (*Ambrosia trifida*) | Resistance is a concern, but poor control due to stalk borers and untimely applications is of more immediate concern |

[1]King et al. 2004.
[2]Collins 2004.
[3]Bennet 2004.

## So What Does the Future Hold?

Herbicide resistance can be included in a common statement with death and taxes. It is a certainty. And if we rely exclusively on glyphosate for weed control, glyphosate resistance is a certainty. When will glyphosate-resistant weeds occur in your field? How fast will glyphosate-resistant weed populations spread throughout Illinois once they begin to occur? We will have to wait and see.

It is very unlikely that new herbicides will come into the market to replace glyphosate in the foreseeable future. Thus, fields that contain glyphosate-resistant weeds likely will be managed by combining glyphosate (to control the non-glyphosate-resistant weeds) with another herbicide specific for the glyphosate-resistant weed species. This combination will increase the cost of weed control and the level of management required. More troubling is the concern that species that have already evolved resistances to other herbicides are probably the most likely to evolve glyphosate resistance.

## References


Bennet, D. 2004. Is ragweed next to resist glyphosate? Delta Farm Press, Sept. 3, 2004.

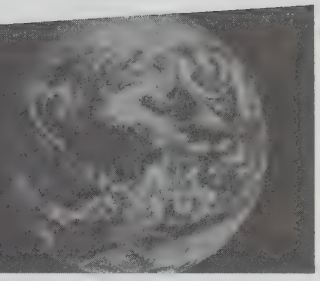
Bradshaw, L.D., S.R. Padgette, S.L. Kimball, and B.H. Wells. 1997. Perspectives on glyphosate resistance. Weed Technology 11: 189–198.

Collins, S. 2004. Potential glyphosate-resistant common ragweed found in Missouri. Corn and Soybean Digest. Aug. 1, 2004.

Heap, I. 2004. The international survey of herbicide resistant weeds. Available at www.weedscience.com. Accessed October 7, 2004.

King, S.R., E.S. Hagood, and J.H. Westwood. 2004. Differential response of a common lambsquarters (*Chenopodium album*) biotype to glyphosate. Weed Science Society of America Abstracts 44: 66.

# Cyberfarm 2005—Illinois FSA GIS Implementation



*Joe Curless and N. Dennis Bowman*

The USDA's Farm Service Agency (FSA) programs help agricultural producers purchase and operate farms, stabilize farm income, conserve land and water, and recover from the effects of disasters.

To determine producer benefits for most FSA program areas, FSA must know the specific crop acreage or other land use information. Also, for many programs, producers agree to certain provisions on their land, such as conservation compliance.

In the past, local FSA staff's only option was to use aerial slides or to visit farms to assist producers with determining acres or other land-based information. Because much of FSA's business is directly related to the land, the agency is in the process of modernizing its maps and related geospatial information.

Illinois FSA is in the process of implementing a geographic information system (GIS) in local field offices. This technology will enable FSA to efficiently manage and make data more accessible, increase productivity, and improve customer service.

The first step in this implementation is establishing a common land unit (CLU) layer. A CLU is the smallest unit of land that has

- a permanent, contiguous boundary;
- common land cover management;
- a common owner; and
- a common producer association.

To accomplish this, the hard-copy aerial maps must be transferred to a digital orthophoto quadrangle (DOQ). Then, reference lines such as farm, tract, and field boundaries; roads; and waterways must be scanned onto the imagery.

Upon receipt of the CLU layers, county FSA offices check the accuracy of the reference lines. Once the CLU data layer is certified, it will supersede aerial photography as official USDA photography.

FSA is integrating GIS layers and global positioning system (GPS) information to increase the efficiency, accuracy, and timeliness of FSA program administration. GPS data layers, ortho-photography, soils layers, public land survey data, and many other data layers can be placed atop one another inside of one GIS project.

GIS and GPS help FSA store and use information on field boundaries of land and attributes for each field, such as field number, crop type, and producer information. Aerial photography, grain bins, private roads, and field boundaries can all be displayed in GIS at the same time. Each of these layers, excluding the aerial photography, has a database associated with it that stores detailed information.

In addition, GIS and GPS technology can help agricultural producers improve production history and farm planning through precision agriculture. Producers can request copies of USDA imagery, farm and field boundaries, and soil data to help them with

- farm planning, such as determining crop planting strategies;
- crop production, such as mapping and monitoring fertilizer and herbicide application; and
- decision making on the farm.

# Asian Soybean Rust: Sampling Protocol, Thresholds, and Scouting

*Suzanne Bissonnette*

This specialized session covers the nitty-gritty of how to actually scout for soybean rust, how to take a sample, what to do with it, and why. The session also addresses the topic of what protocols to follow once the disease is confirmed in the continental United States.

Generally, leaf diseases of soybean have been pretty ho hum in Illinois. We generally see some Septoria brown spot and perhaps some frogeye leaf spot or bacterial blight. Largely, no one is too astonished by these diseases and they cause little yield loss. This attitude will dramatically change when Asian soybean rust makes its way to the continental United States. It's not here yet, but it is very important we become vigilant in early detection so that we can effectively manage this serious disease.

Soybean rust is a fungal disease of soybean that can infect leaves, stems, petioles, and even cotyledons of a soybean plant. It causes significant defoliation of the plant and subsequent loss in yield and death of the plant. The disease spread though 90% of the soybean-growing areas of South America in just 2 years. Our adapted soybean varieties are all susceptible to this disease, so early detection and identification will be critical to mitigating yield losses.

There are two species of the soybean rust fungus, *Phakopsora pachyrhiza* and *P. meibomiae*. *P. meibomiae* is much less aggressive and much less of a threat to the crop compared with *P. pachyrhiza*. So, if one or both of these rusts show up in a field, how can you tell them apart? An easy answer—you can't. The species must be identified and differentiated in a designated plant diagnostic laboratory.

Illinois has developed a state plan to respond to soybean rust, available online at http://www.agr.state.il.us/regulation/soybeanrustprogram.pdf. The Illinois Soybean Rust Program is a coordinated effort between the Illinois Soybean Checkoff Board, Illinois Fertilizer and Chemical Association, Illinois Seed Trade Association, Professional Crop Consultants of Illinois, University of Illinois, University of Illinois Extension Service, Southern Illinois University, National Soybean Research Center at the University of Illinois, USDA–APHIS, USDA–ARS, and the Illinois Department of Agriculture. The purpose of the program is to detect and eradicate soybean rust if and when it occurs in Illinois. Summary points of the state plan follow.

## Predetection Scouting

Early detection and identification of the pathogen will be key to making the right decision about how to best manage the disease for yourself or your clientele.

1) First detectors include producers, 1,500 certified crop advisers, professional crop consultants, University of Illinois Extension, Southern Illinois University Agriculture Department staff, Illinois Fertilizer and Chemical Association membership, seed dealers, and other agricultural professionals.
   - "Look Low As You Go," a soybean rust vigilance-scouting program.
     - State scouting protocol
   - Suspect field observation
     - State plant sampling protocol
     - Prescreening via University of Illinois distance diagnostic digital imaging (DDDI) online diagnostic service available at all university extension unit offices.

## Testing Samples for Soybean Rust

The soybean rust pathogen is on the U.S. Select Agent list produced by the U.S. Department of Homeland Security. This rust pathogen cannot be transported across state lines without the appropriate permit. Testing of suspect soybean rust plant material should be done within the state of Illinois.

The Plant Clinic at the University of Illinois has been designated as a triage laboratory for soybean rust sampling by the National Plant Diagnostic Network (NPDN)

(www.npdn.org). It is the primary diagnostic laboratory for soybean rust unknowns in Illinois.

## Where Should Samples be Sent for Testing?

To avoid overloading the Plant Clinic with soybean rust suspect samples, the University of Illinois Extension DDDI laboratories will act as a prescreening/triage laboratory. If prescreening is bypassed and samples are sent directly to the University of Illinois Plant Clinic, please phone before sending or delivering such samples. The University of Illinois Plant Clinic telephone number is 217-333-0519. The address is Plant Clinic, 1401 W. St. Mary's Rd., Urbana, IL 61802. For those wishing to hand-deliver samples, the clinic location map is available at http://plantclinic.cropsci.uiuc.edu/. A plant clinic specimen data form should accompany any plant sample submitted to the Plant Clinic. The data form is available at the clinic Web site or local extension offices throughout Illinois.

## How Will Samples be Tested for Soybean Rust?

Plant samples will be examined for rust pustules with the aid of a dissecting microscope. Suspect pustules will be sectioned and examined with a compound microscope for the presence of rust spores. University of Illinois and USDA plant pathology specialists may be called to examine suspect positives. The Plant Clinic microscope-mounted, Web-based, live videocamera may then be used to communicate directly with APHIS–PPQ staff in Beltsville, MD. If the sample remains a soybean rust-infected suspect after this initial examination, then tissue will be sent to APHIS–PPQ specialists with appropriate PPQ forms for polymerase chain reaction (PCR) testing. Molecular testing with PCR is a relatively quick method of positive identification of rust to the species level. It is a definitive way to identify *Phakopsora pachyrhizi*. APHIS–PPQ specialists have been designated as the final determinants of an initial soybean rust find in a state. Should soybean rust be confirmed in Illinois, subsequent samples may be tested using the molecular testing PCR technique at the NPDN regional expert laboratory in East Lansing, MI.

## How to Prepare a Sample

Soybean rust may occur on any aboveground soybean plant part. The leaves are the easiest to work with in the laboratory and comprise the typical suspect sample submitted. Ideally, samples should include about 20 leaves that are flat, dry, and between dry paper toweling. They should be packaged in two layers of zipper-locked plastic bags. The bags should be clearly labeled with a permanent marker providing: date, host plant, collector's name, phone number, collection location within the field, location of the field, county, township and section, and nearest intersection. Global positioning system (GPS) information is helpful if available. If the sample is mailed, the seams of the box must be taped shut. It is best to keep the sample refrigerated or on ice until it arrives at the testing laboratory.

## Payment for Samples

The University of Illinois Plant Clinic requires a payment of $12.50 per sample at the time a sample is submitted. Checks should be made payable to the University of Illinois. Samples sent to APHIS–PPQ specialists for PCR testing may or may not require additional payment. Illinois APHIS officials are currently trying to request funds through the National Agricultural Pest Information System program to possibly cover the expense of some testing. At this point, we encourage testing but ask that individuals contact the Plant Clinic before sending samples so that samples can be screened and payment plans can be negotiated.

## Special Confidentiality Note

*It must be noted that when a positive soybean rust case is found in Illinois, the Director of Agriculture or his designate will make the official announcement.* This person will be able to provide resources and answer questions that follow. The Plant Clinic staff will not release results of soybean rust testing publicly and cannot make an announcement directly. National protocol prohibits release of such information until a positive has been confirmed through APHIS–PPQ.

# Influence of Soil Physical and Chemical Properties on Herbicide Availability and Degradation

*Bill Simmons*

Herbicides with soil activity are still an important component of weed control in corn and soybean. These may include both preemergence (PRE)-applied herbicides and postemergence (POST)-applied herbicides with soil activity. The interaction of soil properties, water, and application timing affects the fate and behavior of herbicides, crop response, and potential for carryover. Current research includes efficacy and dissipation of mesotrione (e.g., Lumax and Callisto) and isoxaflutole (e.g., Balance products) over a range of soil pHs. We have ongoing work on soil pH affects on flumioxazin (Valor) and sulfentrazone (Authority and Spartan) injury to soybean. As of this report, it seems that the future of sulfentrazone use in soybean is in jeopardy, bringing flumioxazin and other compounds into great focus in the soybean acres where small-seeded broadleaf weeds are a concern.

In addition, we are doing some "plantback" studies to investigate the dissipation of simazine (Princep) and atrazine after fall and early spring applications. We are doing this to test the idea that in some cases soybean could be successfully grown after a change of cropping plans on fields treated for corn.

In this presentation, I discuss the following topics: 1) the basics of soil interactions with herbicides; 2) the value of residual control in total post systems; soil pH effects on carryover and in-season injury; 3) carryover potential as affected by herbicide, soil, and climatic conditions; and 4) time–dissipation relationships for fall applied herbicides.

Soils contain the organic matter and clay particles that control herbicide sorption and water relations and provide the environment that influences microbial activity. The main herbicide loss pathways in soil are microbial breakdown and chemical breakdown, primarily driven by reactions with water. The effects of soil temperature and moisture on herbicide degradation are straightforward in that degradation mechanisms that involve microorganisms operate best at optimum biological growth conditions. In addition, nonbiological chemical reactions are also typically enhanced with increased temperature. Water is essential for microbial activity and increases aerobic processes up to the point that saturation occurs and gas transfer with the atmosphere is hampered. Soil texture and organic matter content have a surprisingly small effect on carryover because the differences in water and nutrient availability are often counterbalanced by the difference in herbicide adsorption. Thus, a fertile soil, rich in organic matter, may not only promote faster degradation of a herbicide but also have less herbicide available to degrade based on its greater adsorption sites.

Soil pH is important in affecting the stability of some herbicides and herbicide families. High soil pH associated with calcitic soils, over-liming, or proximity to limestone gravel lanes may reduce herbicide degradation and increase carryover. This may be important for triazines and some sulfonylureas. Hydrolysis, an important breakdown mechanism, slows significantly at soil pH values near 7.0.

Biopersistence, or the ability of the parent compound to exist in the soil, is an important feature of soil-applied and some postemergence herbicides and determines the suitability of early preplant applications, residual weed control, and threat of off-site loss to surface or groundwater. To optimize the application timing of soil-applied herbicides, a balance between persistence and requirement for rainfall needs to be considered.

Herbicide persistence is an important property of soil-applied herbicides and some postemergence herbicides that allows for extended weed control. When the herbicide remains unaltered in the soil during the crop season of application, it is an advantage. If a herbicide remains in the soil and is present when a rotational (and susceptible) crop is planted, the persistence causes herbicide carryover. Most herbicides ***do not*** carryover. Degradation rates in the soil under normal environmental conditions typically reduce herbicide concentrations to sublethal levels for rotational crops. Some herbicides have additional safety in that they are not injurious to rotational crops.

Shifts in herbicide application timing to earlier applications have put a premium on herbicide persistence to coincide with weed emergence. In a broad sense, the resistance to degradation and downward movement within the soil profile are both important to obtaining satisfactory weed control.

Glyphosate-resistant soybean treated with glyphosate alone does not allow for residual control of weeds that might germinate after the last POST application is made. What is the value of a residual herbicide either mixed with glyphosate or applied to the soil at planting? Data are presented that address this issue.

# Soybean Aphid Management Update: What to Select From a Variety of Pest Management Tools?

*Matt O'Neal and Kevin Johnson*

Like most of the Midwest, Iowa soybean growers were introduced to a new pest when the soybean aphid, *Aphis glycines* Matsumura (Homoptera: Aphididae), arrived in 2000. And like many other states, Iowa has experienced large populations of aphids (>2,000/plant) in two of the past 5 years that the aphid has been in the state (Lang 2003; M. O'Neal, unpublished data). Although not well understood, there is an apparent oscillation in aphid populations between years with large populations occurring in 2001 and 2003, and low populations (≤500 aphids/plant) occurring in 2002 and 2004.

During 2003 soybean aphid populations in Iowa began to sharply increase early in June (Rice 2003) and by July, >2,000 aphid/plant reported when plants were in full bloom to early pod set (DeWitt and Tollefson 2003). In total, an estimated 4 million acres in Iowa was treated with insecticide to control soybean aphid populations (Landis et al. 2003). In a remarkable reversal, we experienced very low populations of soybean aphids during 2004, with many of our research sites experiencing peak populations of less than 100 aphids/plant (Figure 1). Given the oscillating trend, and the appearance of soybean aphids overwintering on buckthorn (*Rhamnus* spp.) within central Iowa (M. O'Neal, unpublished data), soybean aphid populations may be larger in 2005.

## Soybean Aphid Biology

Soybean aphid has a complex lifecycle with sexual stages found on the primary host plant (buckthorn), and asexual stages occurring on the secondary host plant, soybean (Wang et al. 1962). Soybean aphids migrate to *R. cathartica* from soybean fields, where a sexually reproductive generation produces eggs that overwinter on the plant. In the spring, these eggs hatch and eventually producing alates (winged adults) that migrate back to soybean, arriving in early to mid-June (Fox 2002, Rice 2003). Soybean aphids reproduce asexually while on soybean, increasing their numbers rapidly. Natural enemies can play a key role in suppressing soybean aphid populations both in its native Asia (Liu et al. 2004) and the north central United States (Fox et al. 2004, Rutledge et al. 2004). In Asia, where soybean aphids are rarely a pest, coccinellids (ladybird beetles) are among the most common natural enemies, and soybean aphid colonies typically support parasitism rates of 40% (Liu et al. 2004.). Iowa soybean fields contain many aphid predators (Bechinski and Pedigo 1981), yet large populations of aphids have occurred in two of the past 4 years that the aphid has been in the state (Lang 2003; M. O'Neal, unpublished data).

## Soybean Pest Management in Iowa—More Than Just One Pest

In Iowa, management of soybean aphids is complicated by a 5-year trend of increasing bean leaf beetle, *Cerotoma trifurcata*, populations (Krell et al. 2003). Both present growers with two potential sources of yield loss from direct feeding as well as disease infection because both bean leaf beetle and soybean aphid are vectors of several plant viruses (Clark and Perry 2002). In Iowa, evaluation of the effect of the current recommendation for bean leaf beetle (Bradshaw and Rice 2003) on soybean aphid population management is being conducted. Several foliar-applied insecticides can reduce soybean aphid populations (Ostlie 2002), and insecticides applied as seed treatments may slow soybean aphid establishment and population growth (C. DiFonzo, personal communication). Given that these insecticides are active against both bean leaf beetles and soybean aphid, there is the potential that both could be managed within the same program. A management strategy based on an early and mid-season application of Warrior can manage bean leaf beetle and may reduce incident of bean pod mottle virus (Bradshaw and Rice 2003). Whether a mid-season application of Warrior timed with the emergence of the first generation of bean leaf beetle is effective for controlling soybean aphids is not yet known.

## Soybean Aphid Management

Many questions have yet to be answered regarding the successful management of soybean aphid, including establishing economic thresholds, timing, and method of insecticide application. In Iowa, the soybean entomology laboratory at Iowa State University is attempting to address several of these issues. In this report, we summarize our data from the 2004 field season regarding three projects that address

1) development of economic thresholds for soybean aphid management,

2) measurement of residual activity of early season management programs (seed treatments and foliar-applied insecticides targeting bean leaf beetles) on soybean aphid management, and

3) determination of importance of coverage and active ingredient on insecticide performance against soybean aphids.

## I. Development of Economic Thresholds for Soybean Aphid Management

### *Materials and Methods*

We are participating in an ongoing North Central Soybean Research Program (NCSRP; D. Ragsdale, personal communication) study focused on the development of an economic threshold for application of a foliar insecticide for soybean aphid management. We used an experimental design that has been replicated across five states in an attempt to refine the current action threshold of 250 aphids/plant (Rice et al. 2004). We expanded this experimental design to address how adjusting planting date, a practice recommended for bean leaf beetle management, also may affect soybean aphids.

Initially, we designed our experiment to consist of six treatments that were based on insecticide applications applied when soybean aphid populations reached predefined target densities. These treatments were intended for a randomized complete block design with four replicates of each treatment. Due to low aphid populations, we attempted to establish treatments with a varied number of replications based on within field population densities. This response to low aphid populations required the number of replications to vary by treatment. Within the early-planted soybean, we included the following treatments with number of replications within parentheses: 1) an untreated control (12 replications); 2) an aphid-free plot treated whenever aphid populations are detected (4 replications); 3) insecticide applied on 30 July 2004 (4 replications); and 4) on 6 August 2004 (4 replications). Insecticides were applied in treatments 3 and 4 to establish intermediate aphid populations to determine the impact of varied aphid populations on yield. In the late-planted soybean, we established only two treatments, an untreated control (16 replications) and an aphid-free treatment (4 replications).

Plots were established with approximately 1-m buffers between replicates at Iowa State University Research and Demonstration farms Story County (Central farm) research station. Standard soybean variety and conventional agronomic practices of the Iowa State University Agronomic Research Station staff were used. We established early- and late-planted plots with the four treatments described above to determine the effect of planting date on soybean aphid management. Our "early" plots were planted on 11 May 2004 and our "late" plots were planted on 6 June 2004.

Aphid populations (adults and immatures) established from natural colonization, were sampled each week beginning 8 June 2004 by using whole plant counts of 10 plants per plot from a randomly selected site. The mean number of aphids per plant was used to calculate the aphid days for each treatment replication assuming a population doubling time of 2 days (aphid days =[mean aphids/plant at previous date + current mean aphids/plant/2] × 2). Summing the aphid days accumulated during the growing season (accumulated aphid days) provides a measure of the total aphid exposure that a soybean plant experienced. We measured yield by machine harvest of at least 15 row feet. Standard analysis of variance was conducted to determine whether insecticide applications significantly affected aphid populations and soybean. Accumulated aphid days was arcsine transformed to meet the assumptions for analysis of variance (ANOVA).

### *Results*

In central Iowa, we observed very low aphid populations during 2004 (Figure 1), below the current recommended threshold of 250 aphids/plant. To determine whether low aphid populations can impact soybean yields, insecticide applied on 30 July and 6 August in the early-planted soybean resulted in intermediate populations that were below our untreated plots, but more than the those in the aphid-free plots (Figure 2). Because soybean aphid populations were so low in the later planted soybean, we did not attempt to produce intermediate densities. By the end of the growing season, the insecticide treatments resulted in a significant differences in accumulated aphid days in both the early-planted ($F = 4.19$; df = 3, 17; $P = 0.02$) and late-planted ($F = 86.48$; df = 1, 19; $P = 0.001$) soybean. Despite these differences in aphid densities, we did not observe an impact of accumulated aphid days on yield (Figure 3) in

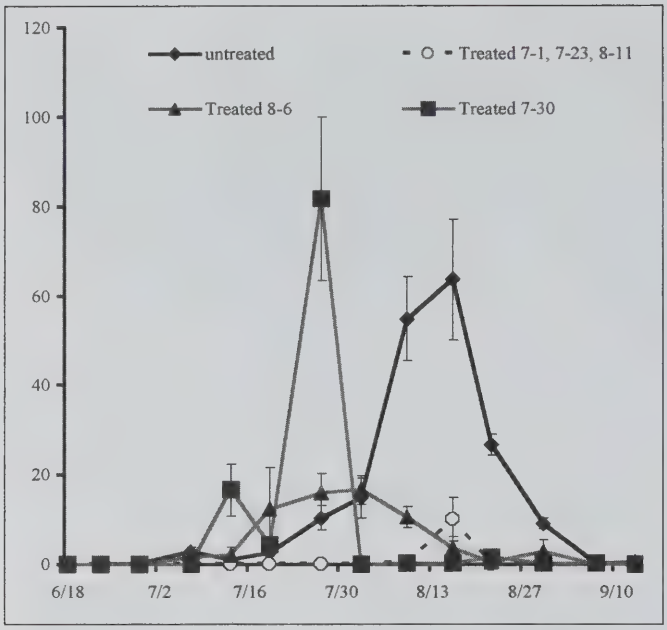



**Figure 1.** Soybean aphid populations in Story County, Iowa, during 2004 on soybean planted on 11 May.

either the early- ($F = 0.13$; df = 1, 17; $P = 0.94$) or late ($F = 0.65$; df = 1, 19; $P = 0.43$)-planted soybean.

## 2. Determination of the Effect of Bean Leaf Beetle Management Tactics on Soybean Aphid Population Growth

### *Materials and Methods*

Several insecticides can reduce soybean aphid populations (Ostlie 2002), including two pyrethroids, Asana (esfenvalerate, DuPont) and Warrior (Warrior, λ-cyhalothrin, Syngenta), which also are labeled for use against bean leaf beetles. The seed treatment Cruiser (thiamethoxam, Syngenta) also may slow soybean aphid establishment and population growth (C. DiFonzo, personal communication). Whether these insecticides can provide protection from soybean aphid when they are applied with the emergence of the overwintering generation or first generation of bean leaf beetle is not yet known. For example, such a program may help actually increase the rate of soybean aphid establishment and population growth by removing the natural enemies of soybean aphids.

We used the following experimental design, originally developed for the comparison of chemical control tactics for early-season bean leaf beetle management. These tactics comprise eight treatments: 1) Cruiser seed treatment (50 g/cwt), 2) Cruiser and Warrior (3.2 oz/acre, 10 d postemergence of plants), 3) Cruiser and Warrior (3.2 oz/acre, at emergence of first bean leaf beetle generation), 4) Warrior (2.5 oz/acre, at 10 d postemergence of plants), 5) Warrior (3.2 oz/acre at emergence of first bean leaf beetle generation), 6) Warrior (2.5 oz/acre, at 10 d postemergence pf plants and 3.2 oz/acre at emergence of first bean leaf beetle generation), 7) Asana (7.7 oz/acre at 10 d postemergence of plants and 9.6 oz/acre at emergence of first bean leaf beetle generation), and 8) untreated control.

Soybean was planted on 3 May with each treatment applied to eight replications in a randomized complete block design at Iowa State University Research and Demonstration farm in Story County. Soybean aphids were sampled each week by using the method described above, and the effect of each treatment on accumulated aphid days was analyzed using analysis of variance (ANOVA).

### *Results*

Again, we observed low populations of soybean aphids across the eight treatments, well below the 250 aphid/plant threshold (Figure 4). Despite these low populations, we did observe significant treatment affects ($F = 2.93$; df = 7, 49; $P = 0.01$). Only two treatments had significantly lower aphid populations than the control, treatment 3 (Cruiser-treated seed and Warrior applied at the emergence of first bean leaf beetle generation) and treatment 7 (Asana applied at 10 d postemergence of plants for first bean leaf beetle generation). There were not significant differences in yield (bushels/acre) among these treatments (J. Bradshaw, unpublished data).

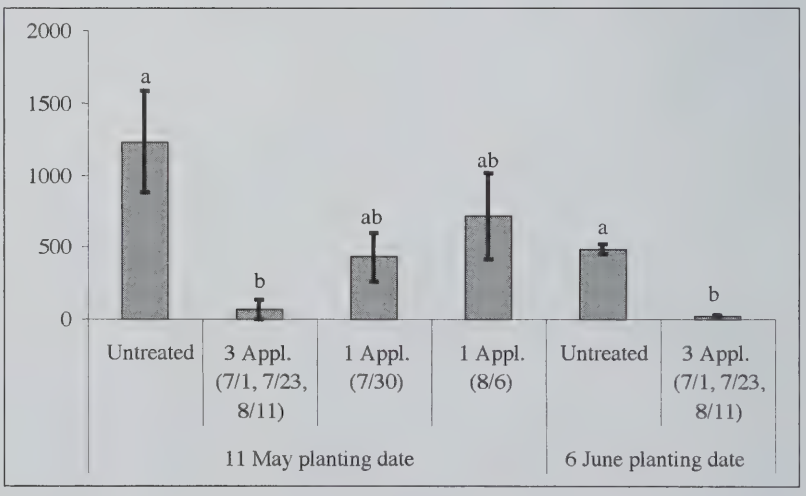



**Figure 2.** Cumulative aphid days experienced in Story County during the 2004 growing season in untreated plots and plots treated with an insecticide (Warrior) at various times. Within each planting date, means labeled with a unique letter were significantly different (P = 0.05). Appl., application(s).

## 3. Determination of Importance of Coverage on Insecticide Performance Against Soybean Aphids

### *Materials and Methods*

In spring 2004, there was interest in the potential of an insecticide applied with a postemergence herbicide to provide protection against soybean aphids (Rice 2004). Potentially convenient, this practice has several drawbacks. Insecticide residual activity may not be sufficient to provide sufficient protection against soybean aphids that arrive in late July. This residual activity also may be reduced by poor coverage of an insecticide that is applied as a herbicide. To reduce the potential for drift, herbicides are applied with lower pressure and larger droplet size than insecticides. Specifically, we were interested in how applying an insecticide as one would a herbicide (herbicide best practice; HBP) affects aphid control versus applications as one would an insecticide (insecticide best practice; IBP).

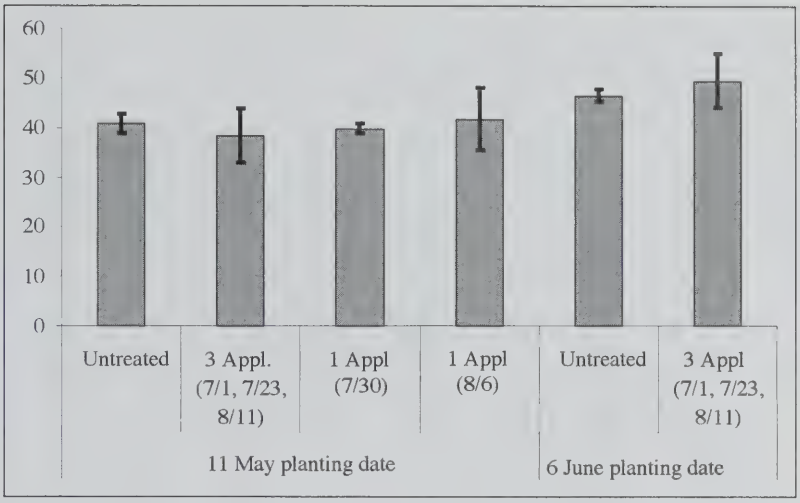



**Figure 3.** Mean yield from plots infested with soybean aphids in Story County during the 2004 growing season. Plots were left untreated or treated with an insecticide (Warrior) at various times. There were no significant differences among treatments. Appl., application(s).

Although soybean aphids were low throughout most of Iowa, we did identify a field that was above threshold (>250 aphids/plant) in southern Iowa at the McNay Research and Demonstration farm in Chariton County. We used this site to determine the importance of spray coverage on soybean aphid mortality and the effectiveness of insecticide treatments for soybean aphid management. Plots measuring 3 by 10 m were arranged within a complete randomized block design consisting of four replications of each treatment. In addition to an untreated control, we compared the efficacy of an organophosphate (Lorsban) alone, this organophosphate in combination with a pyrethroid (Baythroid) and a pyrethroid (Warrior) applied alone. This last treatment was applied using the HBP and IBP methods. Refer to Table 1 for details of the insecticide application methods for each treatment.

Five consecutive plants were counted from a randomly selected site from each replication, and complete aphid counts were performed on these plants. Initial aphid counts were taken on 6 August 2004 before treatments were applied. All treatments were applied using a 3-m, 3-pt mounted sprayer on a 6000 series John Deere tractor. Boom height was set at 6 cm above the canopy and ground speed was ~3 mph. Subsequent aphid counts were next taken on 12 and 20 August 2004, and the effect of each treatment on accumulated aphid days was analyzed using ANOVA.

### *Results*

Initial aphid populations were >250 aphids/plant and did not vary significantly across plots before application of treatments (Figure 5A). After insecticide application, untreated soybean aphid populations increased and were >250 aphids/plant for 6 days (Figure 5B) and 14 days (Figure 5C) after treatment. Each insecticide applications reduced aphid populations below the untreated treatment

**Table 1.** Configuration of insecticide application.

| Insecticide (oz/acre rates) | Nozzle | Total GPA | Pressure PSI | Notes |
|---|---|---|---|---|
| Warrior (3.2) | Tee Jet 8002 XR | 10 | 20 | Pyrethroid applied with HBP |
| Warrior (3.2) | Tee Jet 11002 Twin Jet | 20 | 40 | Pyrethroid applied with IBP |
| Lorsban (24) | Tee Jet 11002 Twin Jet | 20 | 40 | Organophosphate applied with IBP |
| Baythroid (2) and Lorsban (4) | Tee Jet 11002 Twin Jet | 20 | 40 | Pyrethroid and organophosphate tank mix applied with IBP |

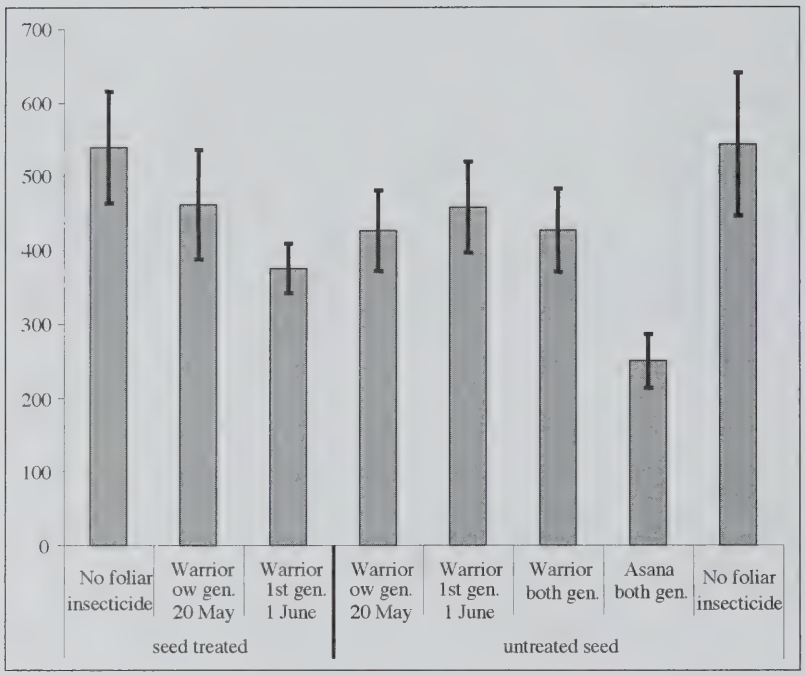



**Figure 4.** Impact of multiple tactics for bean leaf beetle management as control on cumulative soybean aphid days. Treatments include untreated and treated (Cruiser, thiamethoxam, Syngenta) soybean seeds that was treated with and without a foliar insecticides (Warrior, lambda-cyhalothrin, Syngenta and Asana, esfenvalerate, DuPont). The foliar insecticides were applied on 20 May, targeting the overwintering generation (ow gen.), 1 June targeting the first generation (1st gen.), or both generations of bean leaf beetles. Means labeled with a unique letter were significantly different (P = 0.05).

(Figure 5, B and C). However, when Warrior was applied using HBP, soybean aphid populations were an intermediate density between Warrior applied using IBP and the untreated control. Although the HBP reduced populations <250 aphids/plant 6 days after treatment (Figure 5B), plants within this treatment accumulated >1000 aphid days after treatment.

## Discussion

Our findings from 2004 suggest that low aphid populations (<250 aphids/plant; Figure 2) had little impact on soybean yield (Figure 3). These low populations may have an indirect effect on yield through disease spread. At the printing of this report, we have not yet measured the presence of virus in soybean aphid-infested and uninfested soybean. Given the limited impact of low aphid populations on yield, prophylactic treatment of soybean aphids with a seed treatment or an insecticide applied with a postemergence herbicide may have limited value during years like 2004 when aphid populations are low. Such treatments provided limited protection in 2003 (Figure 4), when region-wide aphid populations were low. The cyclic nature of soybean aphid populations between years within North America during the past 5 years suggest that it is likely their numbers will be greater in 2005 than in 2004. To what extant early-season treatments can prevent large populations from developing during years of high soybean aphid immigration is not known.

We have some concern that the residual activity of seed treatments and insecticides applied early in the growing season (May and June; Figure 4) may not be sufficient to provide protection against soybean aphids that immigrate to soybean in late July and August. A factor contributing to reduced efficacy is the method of insecticide application. When insecticides are applied to reduce the potential for drift, as when an insecticide is tank-mixed with a postemergence herbicide (HBP), the coverage within the plant canopy may not be sufficient to reach soybean aphids that are feeding throughout the plant. When we compared a pyrethroid applied as a herbicide (HBP) and as an insecticide (IBP, maximizing coverage), there was a significant difference in aphid survival 14 days post treatment. Interestingly, by maximizing coverage there were no differences in insecticide efficacy across the type of insecticide used (Figure 5). Although we tested a limited number of products, these results suggest that how an insecticide is applied may be more important than the type of insecticide used. Optimizing coverage may be critical to rapidly reduce aphid populations so that the direct feeding damage does not continue. In 2005, we will expand upon these results, developing the best management practices for soybean aphid.

## Acknowledgements

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## References

Bechinski, E.J., and L.P. Pedigo. 1981. Ecology of predaceous arthropods in Iowa soybean agroecosystems. Environmental Entomology 10: 771–778.

Bradshaw, J., and M. E. Rice. 2003. Recent bean leaf beetle and bean pod mottle research. Integrated Crop Management newsletter (www.ipm.iastate.edu/ipm/icm/2003¾-28-2003/blbresearch.html).

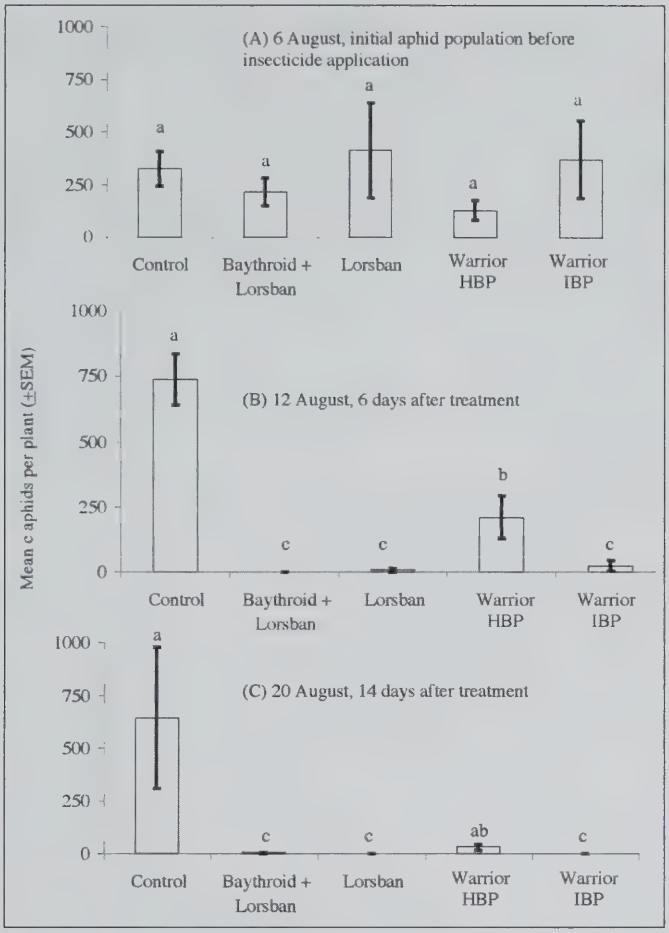



**Figure 5.** Insecticide coverage impacts soybean aphid populations. Insecticide applied with high pressure and small droplet size (IBP), except for HBP, which was applied as a herbicide with low pressure and large droplet size. See Table 1 for sprayer configuration, and rates. Means labeled with a unique letter were significantly different (P = 0.05).


Clark, A.J., and K.L. Perry. 2002. Transmissibility of field isolates of soybean viruses by *Aphis glycines*. Plant Disease 86: 1219–1222.

DeWitt, J., and J. Tollefson. 2003. Soybean aphids making a mark. Integrated Crop Management newsletter (www.ipm.iastate.edu/ipm/icm/2003/8-18-2003/aphids.html).

Fox, T.B. 2002. Biological control of soybean (*Aphis glycines* Matsumura) aphid in Michigan, M.S. thesis. Department of Entomology, Michigan State University, East Lansing.

Fox, T.B., D.A. Landis, F.F. Cardoso, and C.D. DiFonzo. 2004. Predators suppress *Aphis glycines* Matsumura population growth in soybean. Environmental Entomology 33: 608–618.

Krell, R.K., L.P. Pedigo, J.H. Hill, and M.E. Rice. 2003. Potential primary inoculum sources of bean pod mottle virus in Iowa. Plant Disease 87: 1416–1422.

Landis, D., M. Brewer, and G. Heimpel. 2003. Soybean aphid and parasitoids 2003: a survey of NCR-125 cooperating states, in 2003 Michigan state report to NCR-125. http://www.cips.msu.edu/ncr125/StateRpts2003MI.htm.

Lang, B. 2003. Three years of soybean aphid in northeast Iowa, in Proceedings 15th Annual Integrated Crop Management Conference, 3–4 December 2003. Iowa State University, Ames.

Liu, J., K.Wu, K. R. Hopper, and K. Zhoa. 2004. Population dynamics of *Aphis glycines* (Homoptera: Aphididae) and its natural enemies in soybean in northern China. Annals of the Entomology Society of America 97: 235–239.

Ostlie, K. 2002. Managing soybean aphid. University of Minnesota Extension Service (www.soybeans.umn.edu/crop/insects/aphid/aphid_publication_managingsba.htm).

Rice, M.E. 2003. Scout fields now for soybean aphids. Integrated Crop Management newsletter (www.ipm.iastate.edu/ipm/icm/2003/7-14-2003/scoutforaphids.html).

Rice, M.E. 2004. Soybean aphid insecticide and herbicide tank mixing. Integrated Crop Management newsletter (http://www.ipm.iastate.edu/ipm/icm/2004/7-5-2004/tankmix.html).

Rice, M.E., M. O'Neal, and P. Pedersen, and M.E. O'Neal. 2004. Soybean aphids in Iowa - 2004. Iowa State University Extension SP-247.

Rutledge, C.E., R.J. O'Neil, T.B. Fox and D.A. Landis. 2004. Soybean aphid predators and their use in IPM. Annals of the Entomology Society of America 97: 240–248.

Wang, C.L., N.I. Siang, G.S. Chang, and H.F. Chu. 1962. Studies on the soybean aphid, *Aphis glycines* Matsumura. Acta Entomol. Sinica 11: 31–44.

# Injury Across the Landscape: When Herbicide Applications go Awry

*Dawn Nordby and Michelle Wiesbrook*

Every year, the number of drift problems is increasingly higher, keeping applicators, extension specialists and educators, Illinois Department of Agriculture inspectors, and lawyers very busy.

Herbicide drift occurs as two types: particle drift, when fine spray particles move through air at application time; and vapor drift, when the herbicide changes from a liquid phase to a gaseous or vapor phase due to the volatility of the herbicide. Vapor drift can occur at application or for several days after application. Proper steps should be taken before and during all applications to prevent drift. But spring winds can be unpredictable, foiling the best preventative attempts.

Diagnosing crop injury from herbicides can be difficult; however, dealing with ornamentals, which may be unfamiliar, coupled with emotional land- or homeowner(s) can really be challenging. Just as weed species and crops vary in their degree of susceptibility to different herbicides, landscape and garden plants do, too. For example, grapes can be a million times more sensitive to growth regulator herbicides (2,4-D, dicamba) than are corn and wheat, according to Dami et al. (2002). Susceptibility also depends on the age of the plant, whether it is healthy or stressed, and the time of year. It is also important to consider that, under normal conditions, two similar species may seem very different, depending on these factors, regardless of their susceptibility to a herbicide.

Correct diagnosis of injury requires an accurate investigation of the present symptoms together with as much information as possible about the history of the area showing symptoms. Herbicides are sometimes blamed for injury caused by pathogens, nutrient deficiencies or excesses, insects, or adverse weather conditions that cause similar or "look-alike" symptoms. Therefore, it is helpful to have detailed information on each injury situation as well as plant and soil samples for evaluation before attempting to identify the cause of injury.

In identifying injury, several questions need to be answered. What herbicides were recently applied near the affected area? What were the environmental conditions during and after the applications? What should the affected plants look like, considering the age, time of year, and growing conditions? What is the mode of action of the herbicides suspected? What are the expected symptoms? Look for drift patterns and compare similar plants in other "unaffected" areas with those showing injury symptoms. Also, watch for symptoms caused by insects, disease, mechanical damage, wind, drought, and other environmental factors.

With so much to consider, good resources are always appreciated. Over the years, many have relied on the use of photographs of injured crop plants in identifying herbicide drift. Unfortunately, similar resources based on landscape and garden plants are limited. To fulfill this need, field studies were conducted during summer 2004 in Urbana, IL. Several species of ornamental and vegetable plants were treated with various herbicides. Rates used were 1/5 and 1/10×. Injury symptoms were observed and photographed. Similar studies will be repeated in 2005. See below for example photographs and herbicide injury symptoms.

## Plants Included

***Woody plants:*** Redbud (*Cercis canadensis*), red oak (*Quercus rubra*), black walnut (*Juglans nigra*), white pine (*Pinus strobus*), Douglas fir (*Pseudotsuga menziesii*)

***Small shrubs:*** Dwarf lilac (*Syringa patula*), weigela (*Weigela florida*), rose (*Rosa* spp.)

***Perennials:*** Purple coneflower (*Echinacea purpurea*), tickseed (*Coreopsis grandiflora*), gloriosa daisy (*Rudbeckia hirta* var. *pulcherrima*), Russian sage (*Perovskia atriplicifolia*), garden mum (*Chrysanthemum x morifolium*)

***Annuals:*** Ageratum (*Ageratum houstonianum*), salvia (*Salvia splendens*), marigold (*Tagetes erecta*), petunia (*Petunia* x *hybrida*), coleus (*Coleus* x *hybridus*)

***Vegetables:*** Hungarian yellow wax peppers, Better Boy and Celebrity tomatoes, assorted pumpkin varieties

Atrazine injury on mum

Dicamba injury on purple coneflower

Chlorimuron ethyl injury on Russian sage

## Herbicides Included

| | |
|---|---|
| 2,4-D (various) | Atrazine (various) |
| Chlorimuron ethyl (Classic) | Clopyralid (Stinger) |
| Dicamba (Clarity) | Triclopyr (Turflon) |
| 2,4-D + MCPP + dicamba (Trimec) | Glyphosate (various) |

## I. Photosynthetic Inhibitors

These herbicides all inhibit photosynthesis in susceptible plants.

***Triazines:*** Atrazine (numerous premixes), metribuzin (Sencor), and simazine (Princep)

- Characteristics of activity: Translocated in xylem
- Symptoms of injury: Leaf margin burn and interveinal chlorosis

  Older leaves affected first

***Benzothiadiazoles:*** bentazon (Basagran)

***Phenylpyridazines:*** pyridate (Tough)

***Benzonitriles:*** bromoxynil (Buctril)

- Characteristics of activity: Limited translocation
- Symptoms of injury: Necrotic spots, speckles chlorosis, or bronzing

  Activity and injury increase with temperature

***Bipyridiliums:*** Paraquat (Gramoxone Max)

- Characteristics of activity: Nonselective

  Very little translocation
- Symptoms of injury: Water-soaked look early

  Chlorosis/necrosis of plant tissue

  Drift injury occurs as speckling

## II. Amino Acid Synthesis Inhibitors

These herbicides inhibit key enzymes in various amino acid synthesis pathways.

***Imidazolinones:*** Imazaquin (Scepter), imazethapyr (Pursuit), imazamox (Raptor)

***Sulfonylureas:*** Chlorimuron (Classic), primisulfuron (Beacon), thifensulfuron (Harmony GT), nicosulfuron (Accent), halosulfuron (Permit), and tribenuron (Express)

**Triazolopyrimidine sulfonanilides:** Flumetsulam (Python) and cloransulam (First Rate)

- Characteristics of activity: Translocation in both xylem and phloem
- Symptoms of injury: Stunted plants

  Leaf yellowing or chlorosis of leaf margins, purpling of new leaves first

  Slow plant death

  Early symptoms may appear similar to potassium deficiency

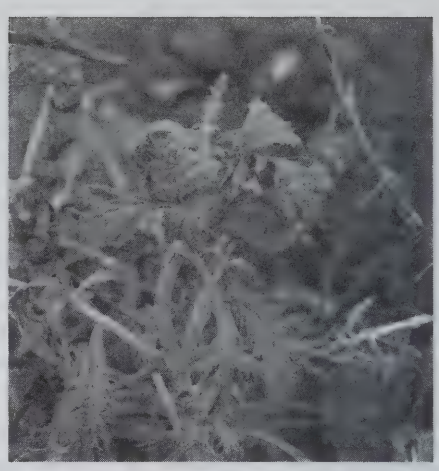
***Phosphono amino acid derivatives:*** Glyphosate (Roundup, Touchdown) and glufosinate (Liberty)

- Characteristics of activity: Nonselective

  Translocated in both xylem and phloem
- Symptoms of injury: Slow chlorosis/necrosis of plant tissue

Clopyralid injury on weigela

Glyphosate drift on tomato



Trimec injury on Russian sage

## III. Protoporphyrinogen Oxidase Inhibitors

These herbicides are primarily foliar-applied and are often referred to as contact herbicides. These herbicides disrupt cell membranes in plants, causing necrosis or cell death.

***Diphenylethers:*** Acifluorfen (Ultra Blazer), lactofen (Cobra, Phoenix), and fomesafen (Reflex, Flexstar)

***N-phenylphthalimides:*** Flumiclorac (Resource) and flumioxazin (Valor)

***Aryl triazolinone:*** Carfentrazone (Aim)

- Characteristics of activity: Little translocation
- Symptoms of injury: Leaf crinkling and stunting

## IV. Lipid Biosynthesis Inhibitors (ACCase inhibitors)

These herbicides inhibit the production of fatty acids.

***Aryloxyphenoxypropionates and cyclohexanediones:*** Fluazifop (Fusilade DX), sethoxydim (Poast Plus), quizalofop (Assure II), and clethodim (Select)

- Characteristics of activity: Translocated in both xylem and phloem
- Symptoms of injury: Chlorosis to necrosis of newest leaf tissue

## V. Plant Growth Regulators

The growth regulator compounds mimic different growth regulating compounds in the plant and may cause a variety of growth abnormalities in susceptible species. The injury symptoms generally are first seen in the newly developing tissue or leaves.

***Benzoic acids:*** Dicamba (Banvel, Clarity, and a component of Marksman and Distinct)

***Phenoxyacetic acids:*** 2,4-D, 2,4-DB, and MCPA

***Pyridinecarboxylic acids:*** Clopyralid (Stinger, and a component of Curtail), fluroxypyr (Starane), picloram (Tordon) and triclopyr (Garlon)

- Characteristics of activity: Translocated in both xylem and phloem
- Symptoms of Injury: Stunting and cupped-shaped crinkled leaves

  Twisting of stems and petioles

  Leaf strapping, stem twisting, puckering, parallel venation (associated with pyridinecarboxylic acids)

## VI. Pigment Inhibitors

These herbicides inhibit the production of certain photosynthetic pigments in the plant.

***Various:*** Clomazone (Command), isoxaflutole (Balance PRO), and mesotrione (Callisto and a component of Lumax and Lexar)

- Characteristics of activity: Clomazone is volatile

  Translocated in xylem (clomazone) and phloem
- Symptoms of Injury: Bleaching or whitening of foliage

  Eventual necrosis and plant death possible

## VII. Shoot and Root Inhibitors

The shoot and root inhibitors reduce the ability of meristems or regions of active cell division to develop and grow normally.

### *Shoot Inhibitors*

***Chloracetamides:*** Alachlor (IntRRo, Micro-Tech), metolachlor (Dual II), acetochlor (Surpass, Harness, TopNotch), and dimethenamid (Outlook)

- Characteristics of activity: Translocated in xylem
- Symptoms of injury: Leaf crinkling and/or drawstring

### *Root Inhibitors*

***Dinitroanilines:*** Pendimethalin (Prowl) and trifluralin (Treflan, others)

- Characteristics of activity: Affect cell division in meristems

  Little translocation

- Symptoms of injury: Stunted plants

  Inhibited root development

  Crinkled leaves

## References

Dami, I., J. Masiunas, and B. Bordelon. 2002. Herbicide drift and injury to grapes. Southern Illinois University at Carbondale, IL

# Where is the IPM in Treating Soybean With a Fungicide/Insecticide Combination in the Absence of Pests?

*Douglas W. Johnson and Donald E. Hershman*

## Introduction

Historically, the Kentucky soybean crop is relatively free of serious insect and disease problems. Although most soybean acres in Kentucky receive herbicide application(s) each year, very few fields are treated with an insecticide or fungicide (Sandell 2003).

Fungicide use was studied extensively in the 1970s and early 1980s by University of Kentucky plant pathologists. Yields from these tests were inconsistent, primarily due to highly variable disease pressure. The two major conclusions of these studies were 1) fungicides rarely produced economic benefit in commercial grain operations, and 2) fungicides seemed to be best suited for seed producers in very specific situations. As a result, almost no fungicides have been applied to soybean since the early 1980s!

Although large-scale outbreaks of soybean insect pests are uncommon, insecticide applications are justified in some fields virtually every year. Common targets are bean leaf beetles on emerging seedlings, and mid- to-late-season applications for Japanese beetles and grasshoppers (Sandell 2003). To date, there has been no need to schedule applications of an insecticide, fungicide, or combination.

## Yield Boost Program

In 2002, Syngenta Crop Protection, Inc. (Syngenta) instituted strip plot trials with foliar sprays of two products, the stobilurin fungicide Quadris® (azoxystrobin) at 6.2 fl oz/acre and a pyrethroid insecticide Warrior® (lambda-cyhalothrin) at 2.56 fl oz/acre. The demonstrations were conducted in numerous grower fields in southern Indiana and Kentucky. The tank mix was applied between soybean plant growth stages (Fehr and Caviness 1977) R3 (beginning pod) and R5 (beginning seed). Syngenta reported estimates of excellent yield increases (average 6.8 bu/acre) from "strip trials." There were no measures of disease or insect pressure or effects on nontarget organisms, and more importantly, the trials were not replicated.

The 2003 cost, based on local product prices and custom application costs, of this tank mix was estimated to be $23.00/acre. With this price, a bushel of beans would only have to be worth $3.38 to pay for the treatment. During summer 2003, soybean (per bushel) prices in western Kentucky varied from the mid-$5.00 range to more than $8.00 before falling back to approximately $7.50 (Riggins 2003). Using the mid-range of these prices ($6.75) and an average yield increase of 6.8 bu/acre, the gross value of this application is $45.90. The net profit is calculated at $22.90 per acre after chemical and application expenses are deducted.

Syngenta was so sure of their 2002 results that they initiated a "Guarantee" for 2003. This program offered to pay for product if the treatment did not work and also to pay if there was not a defined "yield boost."

## Research-Based Recommendations

The use of pesticides to enhance crop yields, even in the absence of damaging pest infestations, is intriguing. It is important to investigate this more carefully because 1) other companies are very likely to implement this calendar-based insecticide/fungicide application approach; and 2) the nontarget impact, especially to beneficial insects and secondary pests, has not been evaluated. These issues need to be addressed through unbiased research of the Cooperative Extension Service (CES).

## Year 1 (2003) Methods

In 2003, we evaluated the following data separately to determine whether the suggested effect was "real" and, if so, what was causing the differences. These data came from the following sources:

1. Two replicated small plot studies at University of Kentucky, Research and Education Center, in Princeton, KY.
2. Three replicated strip plots in growers' fields.
3. Observed six nonreplicated (but paired) strip tests in growers' fields.

4. Summarized yield data from 51 (paired) strip plots in growers' fields.

In all tests, Quadris® (6.2 fl oz/acre) and Warrior® (2.56 fl oz/acre), in combination or alone, were applied between the R3 and R5 growth stages. All data were analyzed using appropriate statistical methods. The treatments are abbreviated as follows: *Q*, Quadris® applied alone; *W*, Warrior® applied alone; *Q+W*, the combination; and *NoA*, no application.

***1. University of Kentucky Research and Education Center replicated plot studies.*** Both studies were carried out on the University of Kentucky Research and Education Center. Both studies were planted as a randomized complete block design (Steele and Tory 1960) with six replications. Also, in both studies, pesticide applications were applied with a $CO_2$ powered back pack sprayer delivering 20 gal/acre at 45 psi. The pesticide treatments in both cases were ***Q***, ***W***, ***Q+W***, and ***NoA***. Data were collected on pest incidence, defoliation, and yield.

University of Kentucky Research Education and Center Test 1. AG3703 RR soybean was planted on May 14, 2003. Plots were six rows wide (15 in.) by 20 ft in length. Treatments were applied at growth stages R3, R4, and R5.

University of Kentucky Research and Education Center Test 2. P94B74 soybean was planted May 16, 2003. Plots were four rows wide (30 in.) rows by 40 ft in length. Treatments were applied at the growth stage R4.

***2. Replicated strip plots in growers' fields.*** In three western Kentucky fields, farmers applied the ***Q+W*** tank mix and ***NoA*** between the soybean growth stages R3–R5. One of these sites was planted with "full-season" beans, whereas the other two fields were "double-cropped" soybean. Plots were a minimum of 40 acres, and each study contained three replications. All production practices, including the application of pesticides and the measurement of yields, were accomplished by cooperating farmers. The fields were scouted weekly by a scout hired through the University of Kentucky Extension Integrated Pest Management (IPM) Program. Data were analyzed and evaluated by us.

***3. Nonreplicated (but paired) strip tests in growers fields.*** Six fields (two in Hickman County, one in Fulton County, and three in Henderson County Kentucky) containing unreplicated, but paired, plots of the ***Q+W*** tank mix and ***NoA*** were monitored. All fields were full-season soybean varieties. All production practices, including the application of pesticides and the measurement of yields, were conducted by the farmers. The fields were scouted weekly by a scout hired through the University of Kentucky Extension IPM Program. Data were analyzed and evaluated by us. Because there was no replication in the field, each field (treatment pair) was treated as a replication.

***4. Nonreplicated but paired strip plots in growers fields.*** A general call for data was sent to Cooperative Extension Service county agents. We received data from 51 fields in eight Kentucky counties, including yield, variety, and planting date information. All production practices were accomplished by the farmers. The fields were not scouted or observed by us. We analyzed and evaluated all the data that were collected. Because there was no true replication in the field, each field (treatment pair) was treated as a replicate.

## Year 1 (2003) Results

***1. University of Kentucky Research and Education Center replicated plot studies.***

**General**

No significant foliar disease developed.

No significant insect populations developed.

Yield increases were due to increased 500-seed weight.

Yield increase due to test weight.

Yield was not increased by seed per pod or pods per plant.

*Phompsis* sp. levels were not significantly affected.

***University of Kentucky Research and Education Center Test 1***

- *Q* and *Q+W*, *but not W*, delayed maturity by a week, regardless of stage of application (R3–R5).
- *Q* and *Q+W*, *but not W*, significantly reduced stem and pod infections (primarily anthracnose).
- Only significant yield increase was with *Q+W* applied at growth stage R4.
- Foliar disease and insects were not a factor.

***University of Kentucky Research and Education Center Test 2***

- *Q* and *Q+W*, *but not W*, delayed maturity by a week.
- No treatments reduced significantly stem or pod disease.
- *Q+W*, *but not Q* or *W* alone, protected yield (3.7 bu/acre).
- Foliar disease and insects were not a factor

***2. Replicated strip plots in growers' fields.***

- *Q+W* delayed maturity by a week in two of three tests.

- *Q+W* reduced stem disease in one of three tests.
- *Q+W* did not reduce pod disease.
- *Q+W* did not significantly affect yields (net economic loss).
- Foliar disease and insects not a factor

3. ***Nonreplicated (but paired) strip tests in growers' fields.***
   - *Q+W* delayed maturity by a week.
   - *Q+W* reduced stem disease.
   - *Q+W* did not reduce pod disease.
   - *Q+W* significantly protected yield (3.42 bu/acre).
   - Foliar disease and insects were not a factor.
4. ***Nonreplicated but paired strip plots in growers' fields.***
   - *Q+W* yields were significantly greater than *NoA*; large range of yields occurred.
   - Significantly greater yields were found in mid-maturity varieties compared with early or late maturities.
   - Greatest yield and economic responses occurred in early maturing varieties.
   - Greatest yields and economic gains were associated with early plantings.

## Year 1 (2003) General Summary

- *Q* and *Q+W* delayed maturity by about 1 week.
- *Q* and *Q+W* tended to reduce stem disease; the impact on pod disease was questionable.
- Insects or foliar diseases did not play a significant role in 2003.
- A trend was noted for greater yields when *Q+W* was applied, but not always. A less obvious trend was noted in double-crop and late-maturing beans.
- *Q* delayed maturity and reduced pod/stem disease; however, yields were not affected.

## Year 1 (2003) "Conclusions"

Data from the 2003 studies provided some evidence of a positive *Q+W* effect on soybean yield and some insight regarding why this response occurred. Neither insects nor foliar diseases seemed to be at densities that would account for yield differences. In 2003, Quadris® alone provided the measurable difference with regard to defoliation and pod and stem disease control. These effects were influenced by planting date and maturity group.

## Year 2 (2004)

In 2004, three small plot experiments were planted at the University of Kentucky Research and Education Center. These experiments were designed to 1) provide a second year of data, 2) observe any similar effects by another stobilurin fungicide, and 3) explore the effects of soybean maturity and planting date on stem and pod disease, and on yield.

To accomplish the first objective, the exact experiments as described in University of Kentucky Research and Education Center tests 1 and 2 were planted in 2004. Only the date of planting (May 6, 2004) varied from the 2003 planting date of May 11. Objective 2 was accomplished by adding two additional treatments to the University of Kentucky Research and Education Center test 2: 1) a different stobilurin fungicide, Headline® (pyraclostrobin); and, 2) Headline® plus Warrior®. Objective 3 was accomplished by designing a new experiment.

For objective 3, a randomized complete block experiment with six replications was planted that contained the following variables: 1) planting date (PD), 2) maturity group (MG) (Norman 1978), and 3) a pesticide application. We used two planting dates that represented early-planted "full-season" beans (May 11) and late-planted "double-crop" beans (June 21). We planted three similar varieties of Asgrow soybean, AG3703 RR, AG4403 RR, and AG5301 RR, with maturity groups 3, 4, and 5, respectively. One pesticide treatment, *Q+W*, and a control, *NoA*, were used. This experiment was a balanced experiment in that each plot received all potential treatment combinations.

As of this report, results of these experiments were just becoming available for analysis, and we are not able to provide them for the proceedings. Hopefully, they can be shared by the time of the conference. In addition, we hope to collect relevant data from other experiments that contain these same treatments.

## Where is the IPM in "Guaranteed Yield Enhancement" Pesticide Applications?

There seems to be no IPM in calendar applications of pesticides to a crop in the absence of any known pests. However, what we know and what we think we know about managing pests changes over time. The source or impetus for this change can come from a variety of sources. When faced with data indicating trends or responses that lie out of the traditional IPM view, we as scientists must use sound research approaches to examine the response and possible causes. We can design experiments to explore questions and raise new possibilities. We appreciate the support of the Kentucky Soybean Growers Association and Promo-

tion Board and the Kentucky Integrated Pest Management program in allowing us to start down this path.

In this specific example, pesticide applications are applied to beans without consideration to any recognized pest levels and measured responses cannot be evaluated with standard statistical tests. Also, timing of applications is based on specific plant developmental stages rather than sound "pest load" criteria. This approach is in direct conflict with the spirit and established practice of IPM. Consequently, we would not recommend this approach without rigorous investigation. Although we have determined that a calendar approach to pesticide application is probably not justified, there may very well be a biologically based explanation, such as pod and stem diseases, for the positive results. Additionally, we demonstrated that other production factors, such as planting date and maturity group, affect these diseases, along with the efficacy of the treatment.

We are a long way from an understanding of the concepts raised in this study. Nevertheless, a research-based approach to investigating this response has allowed us to identify and investigate some previously unrecognized situations. The "yield enhancement" approach to pesticide use does not follow sound IPM principles, and none of the studies addressed impacts to nontarget organisms. However, this example has called attention to the impact of some diseases and established a research effort that may reduce losses to them through improved cultural practices. Most importantly, it emphasizes the importance of keeping an open mind and working to establish the biological relevance of observations.

## References


Fehr, W. and C. Caviness. 1977. Stages of soybean development. SR80. Iowa State University, Ames, IA.

Norman, A.G. 1978. Soybean physiology, agronomy and utilization. Academic Press, New York.

Riggins, S. [ed.] 2003. Monthly market update for November 2003. http://www.uky.edu/Ag/AgEcon/pubs/wkymkt/november.html.

Sandell, Lowell [ed.] 2003. Crop profile for soybeans in Kentucky 2003. http://www.ipmcenters.org/CropProfiles/index.cfm.

SAS Institute. 2000. SAS System for Windows, version 8.1. SAS Institute, Cary, NC.

Steele, R. and J. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill, New York.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# How Early Is Too Early to Plant?

*Emerson D. Nafziger*

Over the past three decades, many Illinois crop producers have changed their attitudes toward early planting, from hesitation to plant early even if the opportunity arose, to eagerly planting as soon as (and sometimes even earlier than) weather and soil conditions permit. This is especially true for corn, but it also has spilled over into interest in planting soybean early as well. Have crop varieties and other inputs changed enough to make it appropriate to plant earlier than was considered reasonable a generation ago, or are we simply willing to live closer to "disaster" that we once feared would result from planting early?

What we consider "early" planting in Illinois depends on our location in the state, but for our purposes here we will define "early" as late March in Southern Illinois, the first week of April in central Illinois, and the second week of April in northern Illinois. A week or two earlier might be classified as "very" early.

Despite greater acceptance of early planting, we need to recognize that we still depend on the weather to make soils fit to plant early. When the urge to plant early overcomes common sense and producers "mud in" the crop in late March or early April, real harm to the crop's prospects usually results. Hence, a first question when considering whether to plant very early should always be, "Is the soil in good condition to plant?" The crop will seldom recover fully from compacted soils that result from field operations when the soil is too wet. Allowing soils to get into good condition before planting is a sound economic decision, even if we end up starting to plant later than we had hoped.

Despite the willingness and even eagerness with which many producers head to the field as soon as soils approach being dry enough in March or early April, there is evidence that such early planting can reduce yields, apart from an effect on plant stand. Averaged over eight site-years in the late 1980s in northern Illinois, corn planted in mid-April yielded about 5 bu/acre less than corn planted in late April. Recent studies have shown similar results, although such yield reduction does not happen every year. Late planting sometimes delays development enough so corn can take advantage of rainfall later in the season, when early-planted corn has matured to the point that it cannot respond as well. More commonly, early-planted corn develops more slowly and unevenly due to low and fluctuating temperatures during vegetative growth, and plant height and even leaf size can be reduced as a result. One of the reasons that early-planted corn did so well in 2004 was the consistently warm weather during May. But that was unusual, and we can hope, but should not expect, yields of corn planted in late March or early April to be higher than yields of corn planted in late April. If we could plant all of our corn on a single day, that day would be during the last week in April.

The expectation that yields of early-planted corn may be a little less than those of corn planted in late April does not mean we should not start to plant early. As a risk management factor, an early start to planting more often means an early finish, and thus a reduction in the chances of being kept from planting by wet weather. The memory of years in which wet weather delayed planting of substantial acreage, especially for those who elected to start planting later, is a powerful incentive for starting to plant early. We may well overestimate the penalty for delaying the start of planting—early planting more often struggles to emerge uniformly and more often requires replanting—but as the general consensus has begun to consider early planting as a hallmark of good, aggressive management, fewer people are willing to wait.

Improvements in genetics, seed production technology, seed testing, and seed treatments have played a large part in making early corn planting more successful. Although there are differences among corn hybrids in time to emergence and in vigor of early growth, few hybrids on the market lack the ability to establish good stands under low soil temperature conditions. Seed treatment fungicides and insecticides, along with more careful seed harvest, drying, and handling and more thorough testing have added to the genetic improvements to make a seed "package" that can emerge under conditions where stands would have failed

completely only a few decades ago. Polymer seed coatings with temperature-sensitive permeability to water have been promoted as a way to further enhance the ability of corn to form a good stand under low soil temperatures, but results in the field have been mixed, especially when temperatures fluctuate after planting.

Some producers still take soil temperatures to estimate when planting should start, but this practice is rapidly losing favor, given the ability of corn seed to emerge under lower temperatures than ever before and the unwillingness of many producers to allow a thermometer to signal when to start planting. I believe it is reasonable to replace the soil thermometer with a decision-making process based on answers to the following: 1) is the soil in good condition to plant?; 2) if the soil and air are cool now, is the weather forecast over the next week for temperatures to rise?; and 3) are all of the protective measures, such as seed treatment, ability to place seed uniformly in the soil, and good seed genetics in place? Finally, it will make sense to most producers to ask these questions with at least one eye on the calendar; if it's the first of March, it may be too early to ask.

A final consideration for early corn planting has to do with seed availability and planting population. One of the real advantages of planting early is that replanting, if it needs to be done, can usually be done early enough to avoid large yield losses due to late planting. On the other hand, it is not clear that the risk of needing to replant starts out very high with early planting, then decreases to near zero as planting is delayed into May. Rather, the need to replant usually results from a heavy rainfall event that occurs soon after planting, regardless of when planting takes place. Heavy rainfall after planting can result in death of germinating seeds due to lack of oxygen, severe soil crusting and inability of seedlings to emerge, herbicides or insecticides moved too close to the seed in high concentration, and an increase in seed or seedling diseases. Sometimes, seeds planted into cool soils, because they germinate and grow more slowly, may survive such an event better than seeds planted into warm soil. A key to replanting readiness is to keep in contact with seed companies, both to know their replant policy (free replant seed is a powerful incentive to risk early planting) and to know what the supply of particular hybrids will be in the event replanting becomes necessary.

Although most of the attention given to early planting is focused on corn, there are some who have advocated early planting of soybean as well. Our planting date work shows that planting soybean in early April, on average, reduces yield more (on a percentage basis) than does planting corn this early (although it does not always reduce yield). Soybean seed is much more fragile than corn seed, and emergence under cool, wet conditions is more difficult for soybean. Even more important, planting delays during May for soybean have much less effect on yield than in corn, hence the penalty for a delayed finish to planting is much less. This is due to the need for favorable weather later in the season for soybean than for corn and also to the favorable response of soybean to warm temperatures during vegetative growth, which are more likely when planting is slightly later. This means that, from a risk management standpoint, it makes sense to finish planting corn before starting to plant soybean.

# Eastern Movement of the Western Bean Cutworm in Midwestern Field Corn

*Marlin E. Rice and David Dorhout*

The western bean cutworm, *Richia albicosta* (Lepidoptera: Noctuidae), is native to North America. It was first reported as a pest of Colorado pinto beans in 1915 and later, in 1954, it was identified as a pest of corn in southern Idaho. Since its discovery in the late 1800s, it has slowly and steadily expanded its known distribution eastward from Arizona to southern Minnesota and central Iowa. The western bean cutworm was known to occasionally occur in western Iowa before 1970, but it was not until 2000 that an economically damaging population was found in field corn. Since then, it has become a recurring economic pest in western and central Iowa. In 2004, western bean cutworms were first collected in Illinois and Missouri.

## Description

***Eggs.*** Western bean cutworm eggs are nearly round with small ridges extending from the top to the bottom of an egg. Eggs are laid in tightly packed, irregularly shaped clusters from 21 to 195 eggs (Figure 1). An average cluster has 52 eggs. Occasionally larger clusters are found. Eggs are white when first laid and turn dark purple a day or two before hatching.

***Larvae.*** Newly hatched larvae are a dull orange with black heads, black pronotum (immediately behind the head) and

**Figure 1.** Western bean cutworm eggs.

**Figure 2.** Western bean cutworm larva.

8–10 black spots on each body segment. Mature larvae have a broad, faint tan stripe along the back, gray sides, no distinctive spots, an orange head, and the pronotum has two broad brown stripes (Figure 2). The brown stripes on the pronotum are a good characteristic to distinguish western bean cutworms from other corn caterpillars. Mature larvae are about 1½ inches in length. There are six, and occasionally seven, larval stages.

***Pupae.*** Pupae are orange-brown, occur in the soil, and are rarely seen.

***Adults.*** The adult moth (Figure 3) is ¾-inches in length and a mixture of brown, gray, and cream. Each forewing has a broad, cream-colored stripe along the front edge of the wing and two distinctive markings—a small, light-colored circular spot just behind and halfway along the stripe, and a buff-colored, boomerang-shaped spot near the end of the stripe. The hind wings are light tan with no distinct pattern.

## Life History in Corn

In western Iowa, moth flight begins in late June, peaks in mid- to late July, and ends during mid-August (Table 1). The female emits a sex pheromone that attracts males. One to 5 days after mating, female moths begin laying their eggs on the upper surface of the top-most leaves, and especially the flag leaf. Females are most attracted to cornfields with tassels just beginning to emerge for egg laying. Females

average 407 eggs laid during their brief lifetime. Eggs hatch in 5 to 7 days. Newly hatched larvae feed on corn pollen and may disperse to adjacent corn plants. Eventually, larvae move to corn ears where they feed on corn silks and the developing kernels.

**Figure 3.** Western bean cutworm adult.

Each of the first five larval stages takes about 5–6 days to develop, with the sixth and seventh instars averaging 7 and 10 days, respectively. Unlike corn earworms, western bean cutworms are not cannibalistic, so several larvae may feed in the same ear. Six larvae per ear have been found in Iowa and 10 larvae per ear have been reported from Colorado. After larvae finish feeding, they chew an exit hole through the cornhusk, crawl to the ground, and form a chamber 3 to 8 inches in depth in the soil. Here, the prepupal stage overwinters. The following spring, the pupae are formed and the adults emerge in early summer. There is one generation a year.

Soil type and moisture in Nebraska has influenced western bean cutworm populations. Sandy soils tended to have larger populations compared with clay soils. Soil moisture, from either rainfall or irrigation, is necessary for adult moth emergence from their pupal cells and can be a limiting population factor, especially in clay soils.

## Damage to Corn

Newly hatched larvae feed in one of two places depending on the stage of corn development. In pretassel-stage corn, the larvae penetrate the flag leaf and feed on pollen in the developing tassel. In tassel-stage corn, larvae feed on shed pollen and eventually move to the silks. Extensive feeding on the silks during pollination may result in incomplete kernel set.

The corn ear is the primary feeding site for larvae. Larvae enter the ear by chewing through the husk or the silks. Unlike corn earworms, which restrict most of their feeding to the ear tip, western bean cutworms feed on developing kernels in both the ear tip and the middle of the ear. This injury to developing kernels can result in constricted and deformed ears. One larva per corn plant at dent stage reduces yield by approximately 3.7 bushels per acre, and estimates from Colorado indicate yield reductions of 30–40% are possible. In addition to this loss of grain, ear molds may develop on the kernels, further reducing the yield quality at harvest.

## Movement Through Iowa to Illinois

Before 2000, the western bean cutworm was considered to be rare in Iowa and economic damage (i.e. exceeding the economic threshold) had never been reported. The first significant damage was observed in 2000 in a cornfield at Holstein. This western Iowa field had approximately 95% of the ears heavily damaged. Two years later, larvae or their damage could be found in most western Iowa counties, and adult moths were being collected in blacklight traps in central Iowa. In 2004, pheromone traps were placed throughout eastern Iowa, including counties bordering the Mississippi River. Adult moths were collected in every trap placed in eastern Iowa (Figure 4), and now the insect is expected to occur in every Iowa county.

In addition, pheromone traps were placed for a single night on 14 July 14 2004 in northeastern Missouri and west central Illinois counties near Iowa. Western bean cutworm adults were trapped in Warren County in Illinois, and in Harrison and Putnam counties in Missouri. These captures are the first documented occurrence of this insect in these two states and represent a significant southeastern movement of the insect from its previously known distribution.

## Scouting

Scouting can be initiated by using either degree days or trap catches. Degree days (base 50°F) for 25, 50, and 75% adult emergence are 1,319, 1,422, and 1,536, respectively. Adult populations also can be monitored using a blacklight trap or a commercial brand (i.e., Scentry®) western bean cutworm pheromone. A common trapping procedure is to cut out windows on the upper half of a plastic 1-gallon milk jug. The pheromone is suspended inside the milk jug and then filled with a 4:1 mixture of soapy water and antifreeze that kills and preserves any captured specimens. The trap can then be placed on a post 3–4 feet high near a cornfield.

Start scouting western bean cutworm eggs in corn based on trap catches or 50% predicted adult emergence. Inspect the upper three or four leaves on 20 consecutive plants at five locations. Hybrids in different stages of development or different leaf characteristics

**Table 1.** Three-year blacklight captures of western bean cutworm adults in western Iowa. Woodbury County, IA, 2002–2004.

| | Western Bean Cutworm Adults | | | |
|---|---|---|---|---|
| **Year** | **First Capture** | **Peak Capture** | **Last Capture** | **Total** |
| 2002 | 28 June | 13 July | 11 August | 12,739 |
| 2003 | 10 July | 1 August | 17 August | 244 |
| 2004 | 5 July | 23 July | 10 August | 531 |

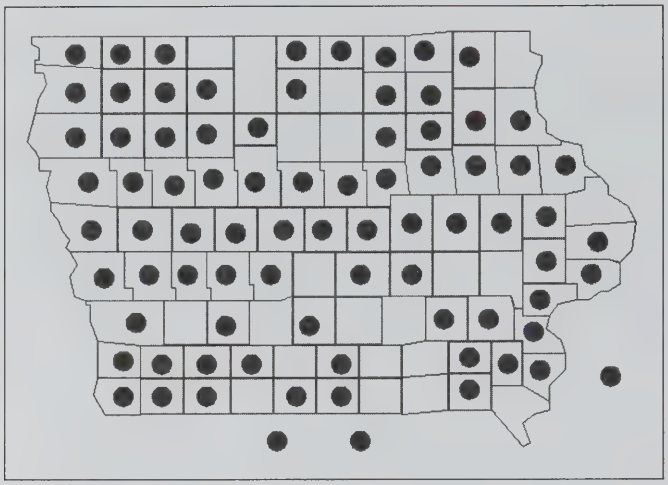


**Figure 4.** Reported distribution of western bean cutworms in 2004.

(upright vs. open) should be scouted separately as adult moths may be more attracted to one hybrid than the other. A nominal threshold recommended by the University of Nebraska is 8% of the plants with an egg mass or young larvae found in the tassel. A simple economic threshold that considers the value of corn and the cost of the insecticide application is shown in Table 2. The values in this table, based on research conducted at the University of Nebraska, assume 3.3% survival of the eggs.

## Management—Insecticides

Timing of an insecticide application is critical. If the tassel has not emerged when the larvae hatch, they move into the whorl and feed on the developing pollen grains in the tassel. As the tassel emerges, the larvae move down the plant to the green silks and then into the silk channel to feed on the developing ear. Once the larvae reach the ear tip and enter the silks, effective control with an insecticide is difficult to achieve. The University of Nebraska recommends that if an insecticide is needed, time the application so that 90–95% tassel emergence has occurred. Or if the tassels have already emerged, the application should be timed for when 70–90% of the larvae have hatched. Remember that eggs that are dark purple hatch in a day.

If an insecticide application is needed, cornfields should be checked for the presence of spider mite colonies. If mites are found, select a product that does not stimulate mite reproduction. Products that contain permethrin (Pounce, Ambush) or esfenvalerate (Asana) have been associated with increased mite reproduction. Other products labeled for western bean cutworm control on corn include Capture 2EC, Lorsban 4E, Penncap-M, Sevin XLR Plus, and Warrior 1EC.

## Management—Transgenic Corn

Genetically engineered corn is available with control against several insect species (Table 3). Only corn with the Bt protein Cry1F offered in Herculex I hybrids has the potential to control western bean cutworms. However, a review of Web-based data, presentations at scientific meetings, and field observations suggests that Herculex I may provide control in the range of only 70–90%. More research is needed to fully understand the performance of Herculex I in a variety of field conditions and insect populations.

## The Future

The western bean cutworm is firmly established as a pest of field corn in Iowa. Its movement into Illinois was unexpected, yet not surprising, considering the adaptive ability of pest insects to expand their range. Whether the insect will become a significant pest in Illinois field corn can only be answered in the future. Fortunately, corn growers have two tools at their disposal to manage the western bean cutworm should it reach economically damaging levels—scouting combined with proper insecticide timing or transgenic corn hybrids.

## References


Ahmad, T.R. 1979. Comparison of heat unit accumulation methods for predicting European corn borer and western bean cutworm moth flights. M.S. thesis, University of Nebraska, Lincoln.

Appel, L.L., R.J. Wright, and J.B. Campbell. 1993. Economic injury levels for western bean cutworm, *Loxagrotis albicosta* (Smith) (Lepidoptera: Noctuidae), eggs and larvae in field


**Table 3.** Pest control spectrum of Bt corn for Lepidoptera.

| Product | Event | Gene | Western Bean Cutworm | European Corn Borer | Corn Earworm | Armyworm | Fall Armyworm | Black Cutworm |
|---|---|---|---|---|---|---|---|---|
| Herculex I | TC1507 | Cry1F | Control | Control | Suppression | Not labeled | Control | Control |
| YieldGard | Mon810 | Cry1Ab | Not labeled | Control | Suppression | Not labeled | Suppression | Not labeled |
| YieldGard | Bt11 | Cry1Ab | Not labeled | Control | Suppression | Not labeled | Suppression | Not labeled |

As stated by seed industry literature.

corn. Journal of the Kansas Entomological Society 66: 434–438.

Blickenstaff, C.C. 1979. History and biology of the western bean cutworm in southern Idaho, 1942-1977. University of Idaho Agricultural Experiment Station Bulletin 592.

Keith, D.L., R.E. Hill, and J.J. Tollefson. 1970. Survey and losses for western bean cutworm *Loxagrotis albicosta* (Smith), in Nebraska. Proceedings North Central Branch Entomological Society of America 25: 129–131.

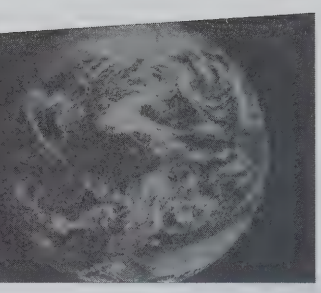
O'Rourke, P.K. and W.D. Hutchison. 2000. First report of the western bean cutworm, *Richia albicosta* (Smith) (Lepidoptera: Noctuidae), in Minnesota corn. Journal of Agricultural and Urban Entomology 17: 213–217.

Peairs, F.B. 2002. Western bean cutworm: characteristics and management in corn and dry beans. No. 5.538, Colorado State University, Ft. Collins. http://www.ext.colostate.edu/pubs/insect/05538.pdf.

Rice, M.E. 2000. Western bean cutworm hits northwest Iowa. Integrated Crop Managment IC-484(22: 163). Iowa State University Extension, Ames, IA. http://www.ipm.iastate.edu/ipm/icm/2000/9-18-2000/wbcw.html.

Wright, B. and R. Seymour. 1996. Western bean cutworm management: Biology, scouting and control of the western bean cutworm. University of Nebraska. http://entomology.unl.edu/pmguides/wbcutwrm.htm.

# Robotics in Agriculture: Asimov Meets Corn



*Tony E. Grift, Matthias Kasten, and Yoshisada*

## Introduction

The human urge to automate our world seems unstoppable. Kasler (2001) claims that the transfer of human intelligence into computer-controlled machines such as robots is an analogy to the fundamental scientific aim to devise theories in a form that makes them reproducible. In essence, we transfer factual data and procedural theories into a computer so that the machine can carry out humanlike tasks. Agricultural operations will inevitably be automated to the extent of economic feasibility. Driving factors are the need for more precise application of materials to prevent environmental damage and increase profitability.

Autonomous full-scale vehicle guidance research in agriculture is well represented in the literature. Excellent references to automated vehicle guidance research in Canada, Japan, Europe and the United States can be found in Keicher and Seufert (2000), Reid et al. (2000), Torii (2000), and Wilson (2000). Much agricultural robotics research has been performed in controlled environments such as robotic picking of cherry tomatoes (Kondo et al. 1996a), cucumbers (Van Henten et al. 2002), mushrooms (Reed et al. 2001), and other fruit (Kondo et al. 1996b). In horticulture, robots have been applied to citrus (Hannan 2004) and apples (Bulanon et al. 2001). Also, milking robots have had much attention, particularly in The Netherlands (Rossing 1997).

Few journal articles are available regarding the development of autonomous robots for field applications. A weed control robot was developed by Baerveldt and Astrand (1998), and Bak and Jakobsen (2004) proposed a small field robot capable of traveling between crop rows to register the locations of crops and weeds by using a camera and global positioning system (GPS) receiver. If the robot is to be used solely for scouting, it can be as small as planet rovers (Biesiadecki et al. 2000, Kuroda 2003). Gomide et al. (2003) used a radio-controlled robotic helicopter to cover a smaller area to improve the resolution, but it required a professionally skilled operator. To obtain detailed local crop state information, field robots are needed that can travel between crop rows and collect data in an autonomous manner. There is much interest in the development of field robots in Europe as evidenced by Wageningen University in The Netherlands, which organized a field robot competition in 2003 and 2004 where students, faculty, and research institutions were represented (Van Straten 2004). AgBo, as described in this article, competed in the 2004 competition.

In the development of autonomous field robots, the emphasis is currently on speed, energy efficiency, sensors for guidance, guidance accuracy, and technologies such as wireless communication and GPS. Although these activities are of scientific interest, the public acceptance of robotic farming will be greatly accelerated by focusing on "bare-bones" field robots that autonomously negotiate crop rows for under $500 in material costs, as described in this article. The bare-bones robot also could serve as a standard research platform to develop robotic scouts, and the focus could be directed to the development of small, precise, and reliable sensors that give information about the status of the crop and the soil.

In addition, there is a need to develop small-scale equivalents for current field operations such as robotic tillage, planting, cultivation, chemical application, and potentially the harvesting of row crops.

## Robotic Crop and Soil Scouting

Remote sensing has been used widely to collect overall information about the crop status as well as soil conditions (Dicker 2002). Although aerial photography can efficiently gather information from a large area, crop-guided scouts, working in proximity to the crop, can collect detailed information about the crop and soil conditions. To date, research has been performed to measure crop stresses in corn, such as nitrogen stress by using a tractor-mounted imaging system (Noh et al. 2003), water stress (Gomide et al. 2003), weed detection (Cho 2002), and disease detection (West et al. 2003). All of these sensors approaches are too large to be directly applied to robotic application. An important problem in the Midwest is insect activity detection such as

of the western corn rootworm. Currently, there is no alternative to human damage assessment by digging up roots and hence the development of a real-time western corn rootworm larvae detector would be of great importance.

Soil scouting is a similar operation where sensors can measure physical and chemical properties to optimize the crop growth and prevent adverse effects to the environment. To measure physical properties, such as density, texture, structure and compaction methods have been devised such as mechanical (Adamchuk 2001a,b), acoustic (Tekeste 2001, Oelze 2003), and Pneumatic (Clement 2000). Oelze (2003) used acoustic backscatter as a method to determine the surface roughness, which may be an important parameter for runoff/erosion prediction. Chemical properties such as pH, moisture, and nitrate content can be measured using near-infrared spectroscopy (Ehsani et al. 1999) as well as electrical resistivity (Banton 1997).

## Robotic Field Operations

A strong argument for replacing a large machine by a small fleet of robots is the reduced compaction potential. Currently, primary tillage is practiced using highly powered tractors to alleviate the compaction caused by the large machines themselves. By replacing the larger machines with a fleet of communicating autonomous robots, a major decrease in compaction and the need to alleviate it could be attained.

Apart from being able to work around the clock, robotic field operations can be more efficient than current operations. A striking example of this is the microspraying approach where minute amounts of chemical are used to directly target weed plants, in contrast to the current practice of treating the whole field with a 1% active ingredient water solution. In addition, in-row mechanical weed control by using robots is being researched, mainly in Europe. Robotic tillage operations may be implemented using acoustics as well (Abu-Hamdeh 2004).

Assuming the total field area remains constant, a number of autonomous robots would have to deliver the same field capacity as a large machine. For example, the amount of material being transported to and from the field in the form of seeds, fertilizers, and harvested crop is not likely to change, and many robots would be needed to transport it. Robotic equivalents for planters and chemical applicators can be developed, but the sheer volume of material during harvesting might justify the conversion of current combine harvesters into the robotic framework.

## The Automated Farm

The lights-off factory, which was envisioned during the industrial automation era, never made it to fruition. Similarly, it is doubtful that full-scale farm automation will become a reality in the near future. It is more likely that a high degree of automation will be combined with manual tasks for operations that are uneconomical to automate. Although the holy grail of farm automation may never become reality, it is an ideal that can give direction to research.

The challenge in producing a highly automated farm operation is in the development of machinery, fitted with sensors and data communication capability. Furthermore, the machinery must be rugged enough to withstand outdoor influences, energy efficient enough to minimize battery charging time, reliable, low maintenance, and safe. As evidenced by the robots described in this article, most of these properties can be approached by producing robots from off-the-shelf components, combined with relatively simply guidance algorithms. GPS-guided robots will benefit from the European Galileo project, which is presumed to become functional in 2009 and deliver high positional accuracy for public use.

One of the most challenging problems lies in developing algorithms that optimize the functioning of a fleet of robots. Not only does this require intelligence in terms of object avoidance, cooperation and conflict resolution are important components as well. It might be feasible to treat the fleet of robots as a mechanical ecosystem where beneficial behaviors emerge automatically when the proper optimization functions are set and cooperative behavior is promoted.

## Mechanical Layout

The width of the robot was set to fit within a standard corn row spacing of 75 cm; and for simplicity of turning and cosmetic reasons, the length was equal to the width. The total height was ~80 cm. Although the majority of components were made out of aluminum, the total weight, including batteries, was ~100 kg.

AgBo was fitted with Bogie suspension (parallel linkage suspension on either side), which guarantees that all wheels are in contact with the ground at all times. In addition, inclination control was implemented, which allows the robot to tilt forward and backward (used to control the angle of attack of the laser guidance unit).

AgBo has four steering modes: 1) front wheel steering (used in crop guidance), 2) all wheel steering (enables short radius turns), 3) crabbing (moves robot laterally), and 4) zero radius turns (spinning in place). The steering also correctly incorporates the Ackermann principle. Each wheel was fitted with 50-W DC brushless gear motor for propulsion and a 20-W DC gear motor for steering.

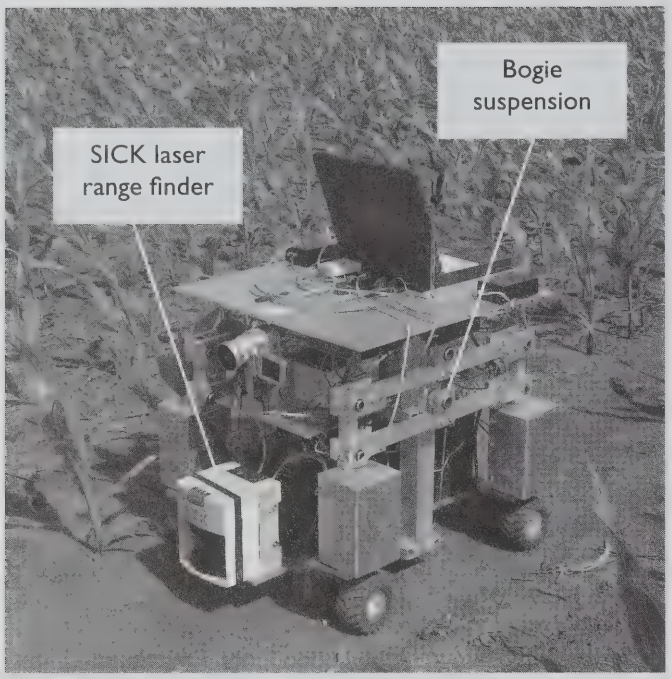



**Figure 1.** AgBo, a flexible, industrial style robot for row crop applications.

## Electronic Layout

The electronic layout of AgBo is shown in Figure 2.

Each wheel was controlled by a wheel control unit that contained a BasicAtom microcontroller (ATOM PRO24-M, Basic Micro, Farmington Hills, MI) under control of a dedicated MBasic program. A major advantage of the BasicAtom microcontroller is the hardware PWM generators, which allow for reliable motor control. The function of the wheel control unit was to generate the appropriate PWM signal for the motors when a steering/driving input is received from the main controller unit. In crop guidance mode, this steering input was transmitted by a laptop computer that interfaces with a SICK (LM291, SICK® AG, Duesseldorf, Germany) laser range finder. In remote control mode, these signals were generated by another BasicAtom microcontroller unit that interfaced with the remote control receiver. An electronic compass (126703CL, Jameco Electronics, Belmont CA; www.jameco.com) was used for end-of-row turning. The laptop computer was used to interface with the SICK laser range finder as well as the electronic compass and to compute the appropriate steering and speed control message for the wheel control units. The communication between the laptop computer and the SICK laser range finder was implemented using RS232C, and the communication with the electronic compass was implemented using a serial peripheral interface (SPI) bus. All other communications were implemented using a controller area network (CAN) bus (Etschberger, 2001). The programming language used for the guidance tasks was "C."

## Guidance

The crop guidance functionality of the robot was based on a SICK laser range finder unit. This unit projects a 180° horizontal laser sheet and calculates the distance to any object in the field of view with an angular resolution of 0.5°. Table 1 shows the specifications of this sensor.

A simplified model of corn stalks was to regard them as perfectly cylindrical shapes, placed in rows at constant distances as shown in Figure 3. The laser scanner measures the shortest distance in 0.5° increments. To control the robot, information is needed regarding the left and right side nearest row. Data filtering was performed using the following steps:

1. Collect distances and associated angles from SICK laser scanner.
2. Convert cylindrical coordinates to Cartesian coordinates within 2-m radius.
3. Discard lateral coordinates outside $15 < |x| < 80$ (this window was chosen arbitrarily)

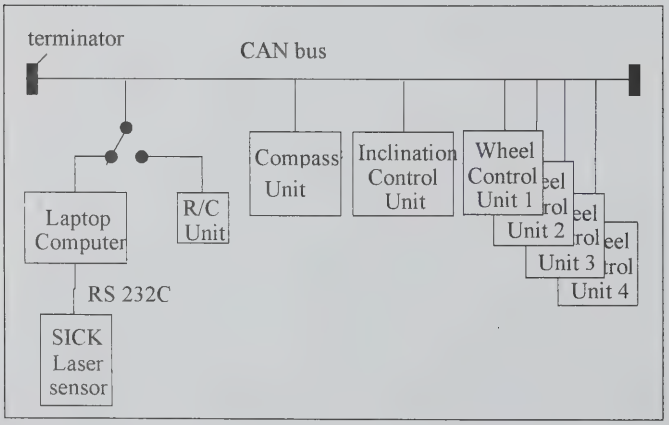



**Figure 2.** Diagram of AgBo's electronic control systems.

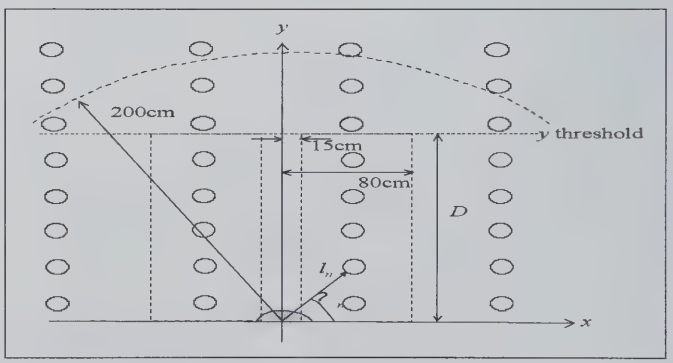



**Figure 3.** Simplified model of corn stalks in the field.

**Table 1.** Specification of SICK laser scanner.

| Type | Scanning angle | Resolution/ Accuracy | Range (10% reflectivity) | Data Interface | Transfer rate | Power consumption | Weight |
|---|---|---|---|---|---|---|---|
| LMS291 | 180° | 10 ± 35 mm | 30 m | RS232 RS422 | 9.6/19.2/38.4/ 500 kb | 20 W | 4.5 kg |

4. Discard longitudinal coordinates larger than threshold *D*. This value is adaptive; *D* is 150 cm during between-row guidance and 80 cm during headland turns.

### *Between-the-row guidance*

The between-row guidance control was based on the difference between the current heading and an aiming point, which was calculated using the filtered data from the SICK laser scanner. The aiming point was simply the mean value of the Cartesian coordinates of the corn stalks. A low pass filtering action was applied over time to compensate for the movement of corn stalks under high wind conditions.

### *End-of-row turning control*

The turning at the end of the row was performed using a series of steps as follows:

1. Detect the end of row by observing loss of data from SICK range finder.
2. Continue moving forward using current heading for 10 s (chosen based on maximum travel speed).
3. Perform zero radius turn through 180° by using electronic compass.
4. Fine-tune robot orientation with latest row by using SICK range finder. Proper alignment was assumed when the average of the corn stalk coordinates (aiming point) is in the center of the detected coordinates.
5. Move transversely (using crab steering) and stop when the robot is in line with the adjacent row using SICK laser sensor. As in step 4, proper alignment was assumed when the average of the corn stalk coordinates (aim point) is in the center of the detected coordinates.
6. Enter adjacent row.

Figure 4 shows the end-of-row turning method of AgBo.

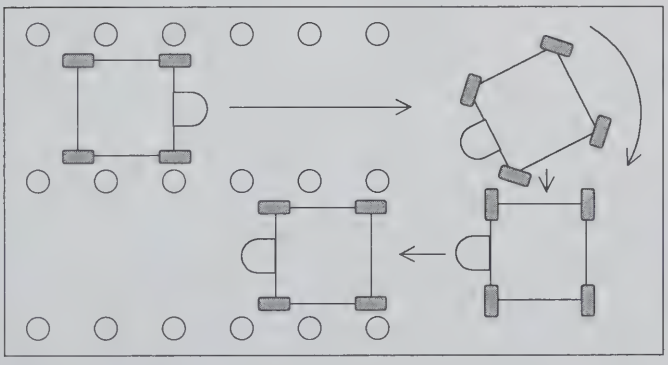


**Figure 4.** End-of-row turning sequence AgBo.

## AgTracker

AgTracker is a rugged, general-purpose robotic platform that was built with reliability, cost, and simplicity in mind. The basic crop guidance functionality was implemented using a single BasicAtom microcontroller. Use involved controlling the speed of the two motors (which subsumes skid steering), receiving and processing information from infrared sensors and the electronic compass, and outputting data to a serial LCD unit as well as interfacing with a remote control receiver in RC mode.

## Mechanical Layout

AgTracker's drive motors are DC brushless high torque types (Astroflight 940P geared motor). The motors have a continuous power output of 750 W and can be run on 12

**Figure 5.** AgTracker, a simple, rugged, low-cost agricultural robotic platform.

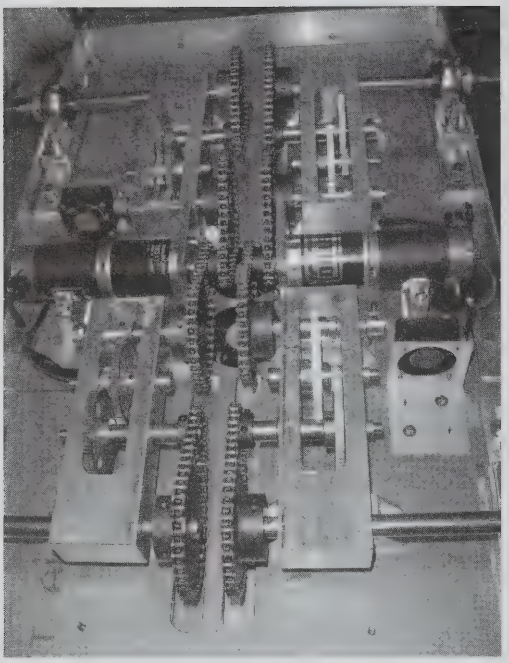


**Figure 6.** Mechanical layout of AgTracker.

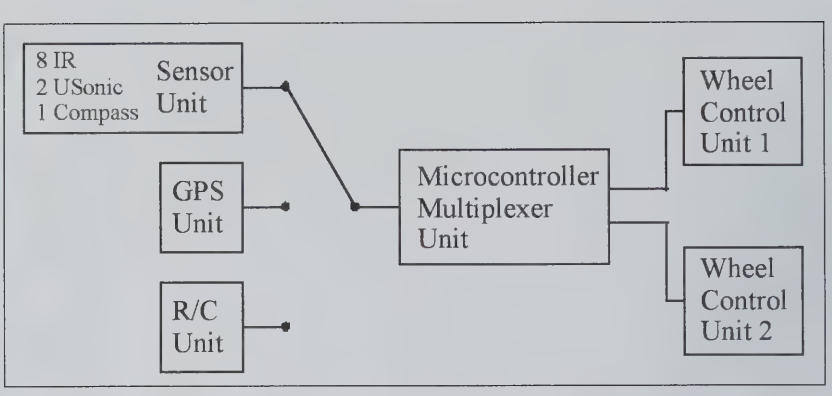



**Figure 7.** Diagram of AgTracker's electronic units with 1) remote control, 2) GPS, and 3) crop guidance modes.

or 24 V. During operation, the motors heated up significantly and thus heat sinks and fans were added to limit this heat buildup.

The output of the motors was geared down significantly using chains and gearboxes, which limits the speed to ~2 m/s. The complete drive train is shown in Figure 6.

## Electronic Layout

AgTracker's electronics layout is much simpler than AgBo's. The electronics were built around a single 40-pin BasicAtom module and no network was required. The advantage of the BasicAtom unit is its built-in hardware pulse width modulation unit, which is very well suited to drive DC motors. To interface the microcontroller with the motors, motor controller boards were used (OSMC Power Unit; www.robot-power.com) To interface with the eight infrared sensors and two ultrasonic sensors, a dedicated board was developed that multiplexed the sensors to the microcontroller unit. The ultrasonic sensors (134105CL, Jameco Electronics, Belmont, CA; www.jameco.com) used analog output voltages, and were connected to analog/digital converter ports on the BasicAtom. The electronic compass (126703CL, Jameco Electronics) had a SPI and output pulses that were counted using a pulse counting command in MBasic. A 20*4 serial LCD unit (LK204-25, Jameco Electronics) was added to display the output of the sensors in real time. Figure 7 shows a diagram of AgTrackers electronic units.

For the programming, BasicAtom's MBasic language was used. This language is a modern Basic variety that supports compilation and allows for simple uploading of the compiled code into the microcontroller by using a fast serial connection.

## Crop Guidance

For crop guidance, AgTracker uses an array of sensors for in-row guidance and end-of-row turning (Figure 8). The crop guidance of the robot was performed by simply attempting to keep an equal distance from the corn stalks on the left and right. As a distance indicator, the average value of the infrared and ultrasonic sensors was used and outliers were removed using a median filter approach.

### *Between-the-row guidance*

When the average left sensor output was higher (closer to stalks) than the average right sensor outputs, the right

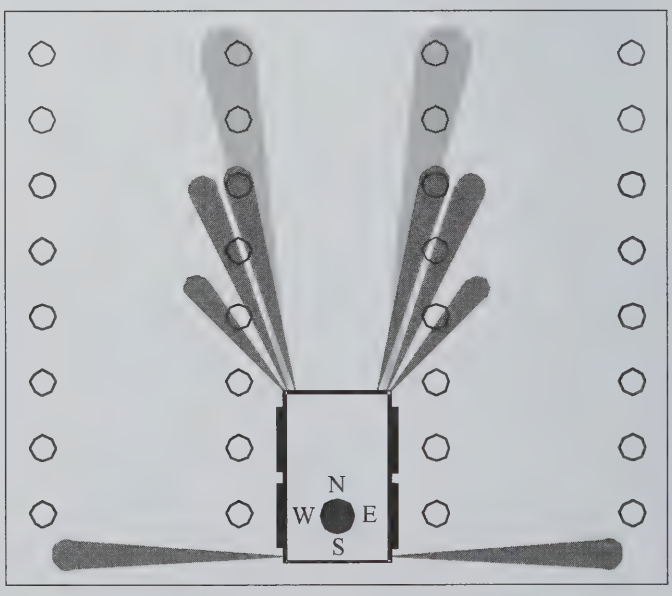



**Figure 8.** AgTracker's sensor arrangenment with two ultrasonic sensors and eight infrared sensors (six long distance, two short distance).

motors were decelerated, which steers the robot to the right and vice versa. The amount of deceleration was proportional to the difference between the average left and right sensor outputs, a classical proportional/integrating action control approach. Constants for the proportional and integrating action were obtained by experimentation and observing the amount of sway in the crop rows.

### *End-of-row turning control*

The end-of-row turning was accomplished using the following steps (Figure 9):

1. Detect the end of row by observing loss of data from infrared sensors.
2. Continue moving forward using current heading for 5 s (chosen based on maximum travel speed).
3. Perform zero radius turn through 90° by using electronic compass.
4. Move perpendicular to the crop rows until the rear sensors "see" the previous crop row.
5. Reverse the robot through 10 cm (time based, ~1 s in 75-cm rows)
6. Turn again in the same direction through 90° by using electronic compass.
7. Move forward into the new row.

## Conclusions

To investigate what type of robot is most suitable for field applications, two robots were built with differing philosophies. AgBo showed to be somewhat excessive in terms of capabilities and cost, estimated at $7,000 material costs. The flexibility of the robot was not truly tested, because simple front wheel steering proved sufficient for between-row guidance. The SICK laser unit provided more information than was used, and significant low pass filtering was applied over time to compensate for wind induced lateral movement of corn stalks and to eliminate the influence of moving leaves. Turning at the end of the row was performed using the spin turn and crab motion. The end-of-row turning method used a compass for two 90° turns, and the SICK laser was used to precisely align the robot to enter the adjacent row. The four-wheel layout of AgBo necessitated the use of bogie suspension, which added significant weight. Also, the SICK laser application required tilt control, which added an additional tilt sensor and linear actuator. AgBo's wheels (10 cm in diameter) proved too small for muddy conditions and even to overcome ruts in dry conditions. In the future, instead of wheels, small tracks may resolve this problem.

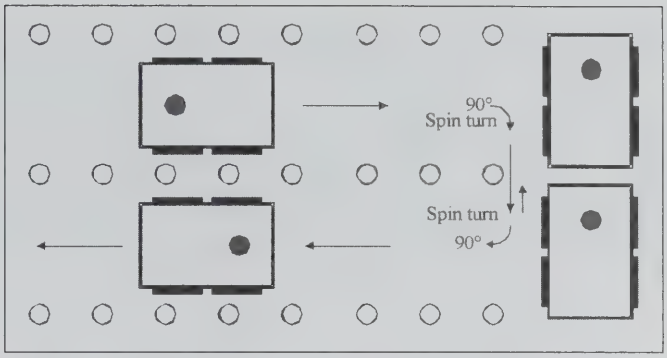



**Figure 9.** End-of-row turning sequence AgTracker.

AgTracker ($500 material costs) proved to be a very robust and effective field robot. Its larger wheels provided sufficient traction under any condition, and the skid steering principle (coupled wheels left and right) eliminated the need for suspension. The sensor layout was cost-effective and the combination of ultrasonic and optical sensors provided sufficient information for between-row guidance. The end of row turning method using the electronic compass was reliable and reproducible. The BasicAtom microcontroller showed the capacity for real time communication with sensors, output to LCD display and motor control.

In conclusion, AgTracker was found to be the most promising agricultural robot. Its performance to price ratio was superior, its fewer parts proved more reliable. and, like AgBo, it negotiated corn crop rows autonomously without damaging plants. In addition, its physical layout made it more rugged and easier to mount sensors and actuators for future development.

## References

Abu-Hamdeh, N.H. 2004. The disturbance of topsoil using ultrasonic waves. Soil and Tillage Research 75: 87–92.

Adamchuk, V.I., M.T. Morgan, and H. Sumali. 2001a. Application of a strain gauge array to estimate soil mechanical impedance on-the-go. Transactions of the ASAE 44: 1377–1383.

Adamchuk, V.I., M.T .Morgan, and H. Sumali. 2001b. Mapping of spatial and vertical variation of soil mechanical resistance using a linear pressure model. ASAE Paper No. 01-1019. ASAE, St. Joseph, MI.

Baerveldt, A. and J.B. Astrand. 1998. Vision-guided mechanical weed-control. Halmstad University. Available at http://www.hh.se/staff/bjorn/mech-weed/. Accessed 21 October 2004.

Bak, T. and H. Jakobsen. 2004. Agricultural robotic platform with four wheel steering for weed detection. Biosystems Engineering 87: 125–136.

Banton, O., M.K. Seguin, and M.A. Cimon. 1997. Mapping field-scale physical properties of soil with electrical resistivity. Soil Science Society of America Journal 61: 1010–1017.

Biesiadecki, J., W. Maimore, and J. Morrison. 2000. The Athena SDM Rover: a testbed for mars rover mobility. Available at http://robotics.jpl.nasa.gov/people/mwm/sdm-mobility/. Accessed 21 October 2004.

Bulanon, D.M., T. Kataoka, Y. Ota, and T. Hiroma. 2001. A machine vision system for the apple harvesting robot. Agricultural Engineering International: the CIGR Journal of Scientific Research and Development. Manuscript PM 01 006. Vol. III

Cho, S.I., D.S. Lee, and J.Y. Jeong. 2002. Weed plant discrimination by machine vision and artificial neural network. Biosystems Engineering 83: 275–280.

Clement, B.R. 2000. Development of a continuously measuring soil compaction sensor. Unpublished M.S. thesis. Department of Food Agricultural and Biological Engineering, The Ohio State University, Columbus.

Ehsani, M.R., S.K. Upadhyaya, D. Slaughter, S. Shafii, and M. Pelletier. 1999. A NIR technique for rapid determination of soil mineral nitrogen. Precision Agriculture 1: 217–234.

Etschberger. 2001. Controller area network. IXXAT Press, 88250 Weingarten, Germany.

Gomide, R.L., L. Tian, and F.A. de Carvalho Pinto. 2003. Thermal and color near-infrared spectral remotely sensed scanners to detect in-field soybean and corn water stress variability. Paper No. 03-3127. ASAE, St. Joseph, MI.

Hannan, M.W. and T.F. Burks. 2004. Current developments in automated citrus harvesting. Paper No. 04-3087. ASAE, St. Joseph, MI.

Kassler, M. 2001. Agricultural automation in the new millennium. Computers and Electronics in Agriculture 30: 237–240.

Keicher, R. and H. Seufert. 2000. Automatic guidance for agricultural vehicles in Europe. Computers and Electronics in Agriculture 25: 169–194.

Kondo, N., M. Monta, and T. Fujiura. 1996a. Fruit harvesting robots in Japan. Advances in Space Research 18: 181–184.

Kondo, N., Y. Nishitsuji, P.P. Ling, and K.C. Ting. 1996b. Visual feedback guided robotic cherry tomato harvesting. Transactions of the ASAE 39-6: 2331–2338.

Noh, H.K., Q. Zhang, B.S. Shin, and S. Han. 2003. Multispectral image sensor for detection of nitrogen deficiency in corn by using an empirical line method. Paper No. 03-1135. ASAE, St. Joseph, MI.

Oelze, M.L., J.M. Sabatier, and R. Raspet. 2003. Roughness measurements of soil surfaces by acoustic backscatter. Soil Science Society of America Journal 67: 241–250.

Reed, J.N., S.J. Miles, J. Butler, M. Baldwin, and R. Noble. 2001. Automatic mushroom harvester development. Journal of Agricultural Engineering Research 78: 15–23.

Reid, J.F., Q., Zhang, N., Noguchi, and M. Dickson. 2000. Agricultural automatic guidance research in North America. Computers and Electronics in Agriculture 25: 155–167.

Rossing, W. and P.H. Hogewerf. 1997. State of the art of automatic milking systems. Computers and Electronics in Agriculture 17: 1–17.

Tekeste, M.Z., T.E. Grift, and R.L. Raper. 2002. Acoustic compaction layer detection. ASAE Paper No. 02-1089. ASAE St. Joseph, MI.

Torii, T. 2000. Research in autonomous agriculture vehicles in Japan. Computers and Electronics in Agriculture 25: 133–153.

Van Henten, E.J., J. Hemming, B.A.J. Van Tuyl, J.G. Kornet, J. Meuleman, J. Bontsema, and E.A. van Os. 2002. An autonomous robot for harvesting cucumbers in greenhouses. Autonomous Robots 13: 241–258.

Van Straten, G. 2004. Field robot event, Wageningen, 5-6 June 2003. Computers and Electronics in Agriculture 42: 51–58.

West, J.S., C. Bravo, R. Oberti, D. Lemaire, D. Moshou, and H. Alastair McCartney. 2003. The potential of optical canopy measurement for targeted control of field crop diseases. Annual Review of Phytopathology 41: 593–614.

# Whatever Happened to the Pesticides in the Groundwater Management Plan?

*Warren D. Goetsch, Susan J. Barron, Kevin W. Rogers, and Dennis P. McKenna*

The Illinois Department of Agriculture (IDA), under the Illinois Pesticide Act and a cooperative agreement with the U.S. Environmental Protection Agency (EPA) regarding the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), is the state lead agency for the regulation of pesticide use in Illinois. The department is responsible for managing pesticide use to prevent adverse effects on humans and the environment (415 ILCS 60/2).

In 1984, the U.S. EPA issued an overall groundwater protection strategy that summarized what was known about protecting groundwater and set out a general role for the agency. In 1987, the U.S. EPA proposed a specific strategy for addressing concerns about pesticides in groundwater. The U.S. EPA's adopted approach is to continue the nationwide regulation of pesticide use, augmented by strong state and tribal roles in the local management of pesticide use to protect groundwater. Although this approach has never become codified in the regulations implementing FIFRA, many states are voluntarily implementing the provisions of generic plans for their potential groundwater protection benefits (U.S. EPA 1987, 1991).

During the following 10 years, various strategies, reports, papers, and guidance documents were issued that further defined the role of the U.S. EPA, as well as states and tribes, in the regulation of pesticides and the protection of the environment. What ultimately emerged was a proposal envisioning continued national pesticide registrations coupled with additional state or county restrictions on use based on specific groundwater concerns. The approach would build upon the existing federal system of categorizing pesticides and give states the ability to customize their individual regulatory scheme. (FIFRA categorizes pesticides into two major categories, general use and restricted use, and specifies certain use restrictions accordingly.) In addition, states have the ability to adopt more restrictive use requirements to meet state-established goals and priorities (U.S. EPA 1991).

Specifically, the U.S. EPA proposed the creation of a new "subcategory" of product registration status between the existing restricted use designation and final product suspension and/or cancellation. Individual pesticides that had been detected in groundwater as a result of normal use could continue to be used only if the use was consistent with the various provisions of a state-developed compound-specific pesticide management plan (PMP) (U.S. EPA 1991).

States, at their own discretion, could choose to develop these compound-specific PMPs to preserve a product's registration. PMPs would be developed by states and reviewed and approved ("concurred") by the Federal Government. To assist states in this process, the U.S. EPA provided guidance regarding the various components that should be present in a PMP. The Federal Government also provided limited funding as part of ongoing FIFRA-implementation cooperative agreements with the states for the development of generic pesticide management plans. In June 2000, under the leadership of the IDA, the Pesticide Subcommittee of the Interagency Coordinating Committee on Groundwater approved the *Illinois Generic Management Plan for Pesticides in Groundwater* (IDA 2000). The management plan describes the framework to be used by the state of Illinois for addressing the risks of groundwater contamination by pesticides.

## Current Illinois Approach

The Illinois management plan relies on the Department's groundwater monitoring well network and the Illinois Environmental Protection Agency (IEPA) public water-supply well pesticide-monitoring subnetwork to determine the occurrence of pesticides in groundwater and whether there are significant spatial or temporal trends in pesticide concentrations. The management plan requires action by the IDA when pesticides are reported at concentrations greater than 10% of the groundwater reference value (or the detection limit if 10% of the reference value is less than the detection limit). If pesticides are detected at these

concentrations, the IDA will conduct, with assistance from the Interagency Committee on Pesticides, the Interagency Coordinating Committee on Groundwater, the registrant, and other state and federal agencies, an evaluation to determine the appropriate course of action. At the very least, the presence of a pesticide in groundwater in concentrations greater than 10% of the reference value would initiate a cause investigation. The components of the response plan in the *Illinois Generic Management Plan for Pesticides in Groundwater* that apply to the groundwater monitoring network are as follows:

- ***Notify pesticide registrant.*** Notification of the pesticide registrant of the occurrence of a pesticide in groundwater is important because the registrant may have obligations to the U.S. EPA to report such detections. In addition, registrants may offer both technical and financial assistance to address well contamination, investigate causes, develop best management practices (BMPs) or additional use restrictions, and work with producers to reduce chemical transport.
- ***Identify cause.*** The IDA will, to the extent practical, evaluate the cause of contamination in an effort to determine whether the presence of a pesticide in groundwater is the result of labeled uses or a nonlabeled use, such as a spill or accident, a point source or other use in violation of the product label. The investigation into the factors related to the presence of a pesticide in groundwater may include additional sampling of any affected wells and other water-supply or monitoring wells in the immediate area. If the pesticide in groundwater is due to a spill or other nonlabeled use, the IDA will take corrective action to ensure cessation of the nonlabeled use and any necessary remediation.
- ***Perform vulnerability assessment and define response areas.*** In cases of contamination as a result of a labeled use, this step will include a variety of activities specifically targeted at evaluation of the site conditions that may contribute to pesticide movement to groundwater and wells. The vulnerability assessment will focus on soil and hydrogeologic conditions, well depth and construction, cropping patterns, and compound use. The results of the evaluation will be used to identify the response area that will become the focus for actions to prevent further degradation of groundwater quality.
- ***Expand monitoring.*** The decision to expand monitoring will depend on the results of the investigation to determine the cause of the presence of a pesticide in groundwater. Contamination of properly constructed monitoring wells as a result of a labeled use would likely result in increased sampling of the impacted wells. In addition, other wells in the immediate area may be sampled to evaluate the extent of contamination.
- ***Encourage adoption of voluntary best management practices.*** If a voluntary best management plan is selected, the results of user surveys to measure adoption of best management practices and groundwater monitoring will be used to measure the success of the response.
- ***Impose use restrictions.*** If the extent or magnitude of the contamination continues to increase in the response area, the IDA will identify additional use restrictions as part of a mandatory management plan. Such restrictions might include imposing setback distances from wells, reducing application rates, or prohibiting use on certain soils within the response area.
- ***Prohibit use.*** If pesticide concentrations continue to exceed the groundwater reference value in spite of previously imposed use restrictions under a mandatory management plan, the IDA, in consultation with the registrant, the Interagency Committee on Pesticides, and the Interagency Coordinating Committee on Groundwater, would evaluate the need to prohibit use within the response area.
- ***Exceedence of a groundwater reference value.*** If a groundwater reference value is exceeded, mandatory changes in management practice would be required. The extent of these changes will depend on the extent of contamination, any trends in concentration, and an evaluation of the effectiveness of any existing best management practices.

The *Illinois Generic Management Plan for Pesticides in Groundwater* targets assessment monitoring to areas where aquifer materials occur within 50 ft of land surface (Figure 1). These aquifers have been demonstrated to be vulnerable to contamination by pesticides as a result of labeled uses (Goetsch et al. 1992, Schock et al. 1992). In 1995, the IDA contracted with the Illinois State Geological Survey (ISGS) and the Illinois State Water Survey (ISWS) to design and construct a statewide groundwater monitoring well network for use with future pesticide management plans. The monitoring well network had three initial goals: 1) provide data to test the utility of a map of aquifer sensitivity to contamination by pesticide leaching as a predictive tool for pesticide management plans; 2) provide data on the variability of the occurrence of selected agricultural chemicals within selected units of the aquifer sensitivity map; and 3) guide sampling to determine whether the occurrence of selected agricultural chemicals varies seasonally and over longer periods of time.

## Illinois' Monitoring Well Network

The current monitoring network is designed to provide statistically reliable estimates on the occurrence of selected pesticides in groundwater within shallow aquifers (depth

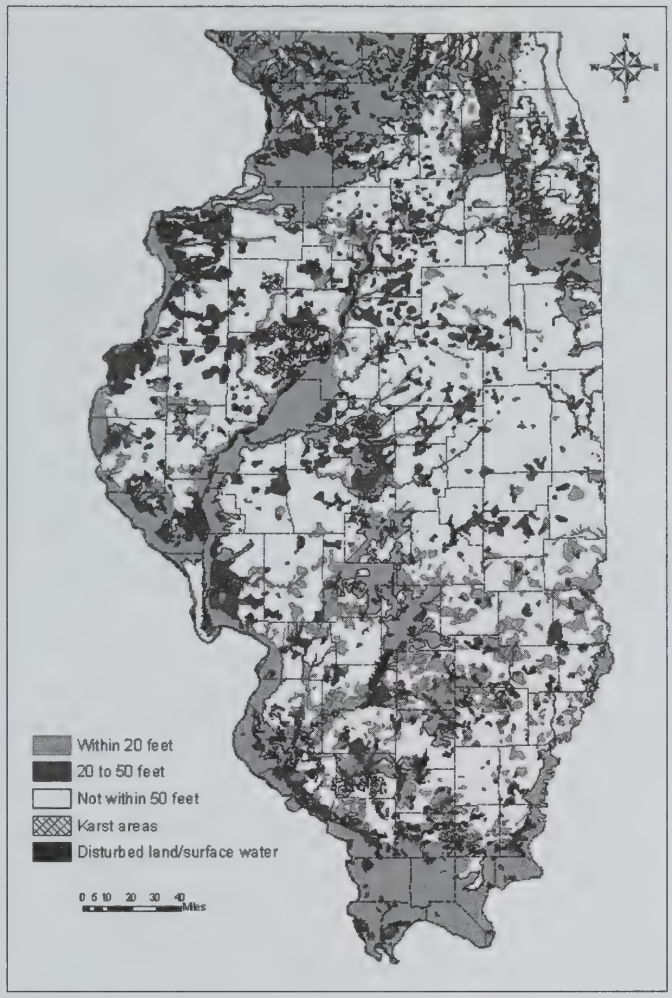



**Figure 1.** Depth to uppermost aquifer within 50 ft of land surface (Keefer 1995).

to the top of aquifer material less than 50 ft below land surface) in areas of corn and soybean production. Occurrence is defined as the presence of a specific pesticide at concentration above the minimum reporting level. The network was designed to determine the regional impacts of pesticide leaching from nonpoint sources, not the impacts of site-specific point sources. The network is not a research program, but a tool for the management of pesticides in Illinois. Consequently, the pesticides selected as analytes are those with high use in Illinois or previously detected in groundwater in Illinois or other midwestern states. Also, reflecting the management tool approach is the decision to set minimum reporting levels at a maximum of 5% of the groundwater reference value, but not to expend limited laboratory resources on detecting pesticides at very low concentrations (Table 1). Both the monitoring network and the Department Pesticide Laboratory operate in compliance with U.S. EPA-approved quality assurance project plans.

The network currently consists of 157 shallow groundwater-monitoring wells located throughout the state (Figure 2). Well depths vary from 10 to 83 ft. Wells are constructed of 2-in. inside diameter (I.D.), polyvinyl chloride (PVC) well casing. Most wells have a 5-ft-long slotted PVC well screen. Each well is located in public rights-of-way adjacent to row crop fields. All of the network wells are installed in areas where aquifer materials occur within 50 ft of land surface. An additional 19 wells were installed in areas of no known aquifer materials within 50 fet and are considered nontarget monitoring wells. These wells are not monitoring the same target aquifer materials and therefore are excluded from statistical analysis with the primary 157 wells.

In 2000, the Department decided to shift the emphasis of the monitoring network from time-series sampling of a relatively few wells to a long-term monitoring emphasis to support implementation of the state's *Generic Management Plan for Pesticides in Groundwater*. Under the sampling plan, each well in the network is sampled once during a 2-year period to provide data on the occurrence of the selected pesticides in shallow groundwater. The ISGS and ISWS conducted a one-time sampling of the network beginning in the fall 1998 and sampled the network from September

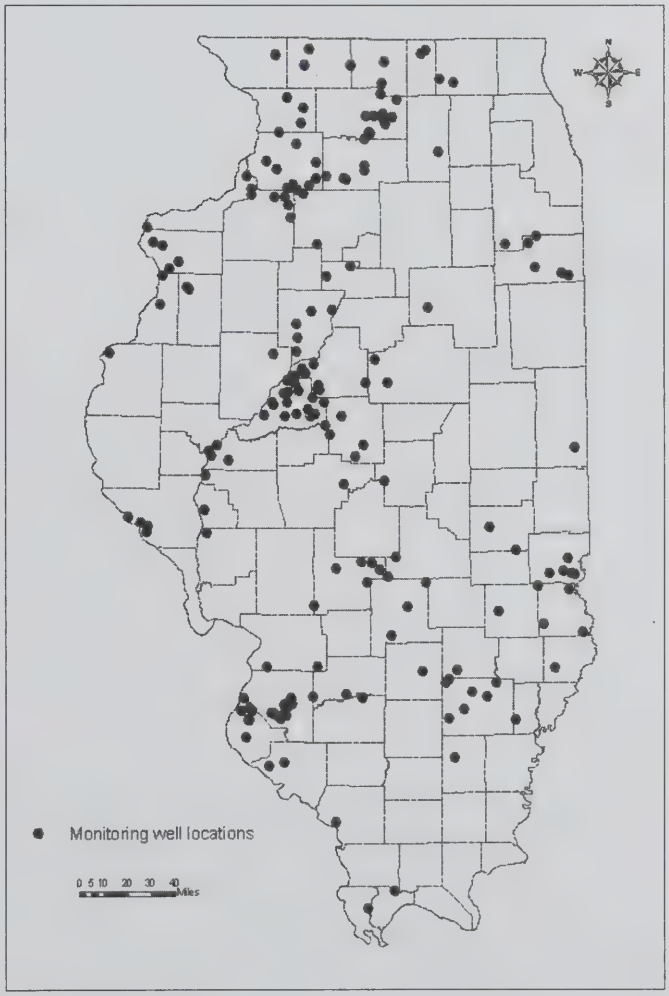



**Figure 2.** Monitoring well locations.

**Table 1.** Minimum reporting levels, action levels, and groundwater reference values for analytes. DEA, DIA. and DEDIA were added in the 2000–2002 sampling period.

| Analyte | Minimum Reporting Level (µg/l) | Action Level (µg/l) 1 | Groundwater Reference Value (µg/l)2 |
|---|---|---|---|
| Acetochlor | 0.15 | 0.2 | 2 |
| Atrazine | 0.15 | 0.3 | 3 |
| Desethylatrazine (DEA) | 0.15 | — | — |
| Desisopropylatrazine (DIA) | 0.15 | — | — |
| Deethyldesisopropylatrazine (DEDIA) | 0.15 | — | — |
| Bromacil | 1.0 | 9 | 90 |
| Butylate | 1.0 | 4 | 40 |
| Metolachlor | 1.0 | 10 | 100 |
| Metribuzin | 1.0 | 20 | 200 |
| Prometon | 1.0 | 10 | 100 |
| Simazine | 0.4 | 0.4 | 4 |

[1] Action level equals 10% of the groundwater reference value.
[2] Reference values from Illinois Groundwater Standards 35 IAC 620.410.

2000 through June 2001. The IDA assumed responsibility for all sampling in July 2001. The IDA will continue to sample the entire network of wells in 2-year cycles.

## Monitoring Well Network Sampling Results

Three rounds of sampling of the monitoring wells have been completed. During these periods, analytical detection levels and minimum reporting levels have varied. To allow comparison between the sampling periods, the following data on the frequency of occurrence reflect the presence of a pesticide at or above the minimum reporting levels used in the most recent sampling round (2002–2004; Table 1). The overall frequency of occurrence refers to the presence of any pesticide, or multiple pesticides, from a single groundwater sample. For example, the occurrence of two pesticides present in a single well sample at concentrations above the minimum reporting level is considered a single detection above the minimum reporting level.

From September 1998 through August 1999, samples were collected from 112 network wells and analyzed for the presence of 14 pesticides (Mehnert et al. 2001). Results indicate an overall frequency of occurrence of 6.3%. Results of the second-round sampling of the network wells (148 samples collected between September 2000 and August 2002) indicate an overall frequency of occurrence of 3.4%. Atrazine was detected in three samples and two of those samples had concentrations (0.58 and 0.85 g/l) above the action level of 0.3 g/l. Cyanazine, metribuzin, and metolachlor were each detected in one sample, but none of those samples had concentrations above levels of concern.

Results of the most recent sampling period (142 samples collected from October 2002 through September 2004) indicate that parent pesticides were detected in 3 of the 142 samples (2.1%). Atrazine was detected in two samples and metolachlor was detected in one sample. None of those samples had concentrations above levels of concern. This most recent sampling period was the first to include the atrazine degradates as analytes. One or more of the atrazine degradation products, (desethylatrazine [DEA], desisopropylatrazine [DIA], and desethyldeisopropyl atrazine [DEDIA], were present above the minimum reporting levels in 18.3% of the samples. In the current round of sampling (2004 through 2006), the department has added metabolites of the chloroacetanlide herbicide to the list of analytes.

The *Illinois Generic Management Plan for Pesticides in Groundwater* requires the IDA to conduct an investigation of the cause if pesticides are detected at concentrations greater than 10% of the groundwater reference value. If selected pesticides for which preventive notification is required under the Illinois Groundwater Protection Act are detected in groundwater, e.g. atrazine, the IDA is required to resample the well within 30 days of receipt of laboratory results. Because U.S. EPA concurrence with the Pesticide Management Plan in February 2001, only one monitoring well sample contained pesticides at concentrations greater than 10% of the groundwater reference value (atrazine parent compound). The department immediately resampled the well and found the atrazine concentration had returned to a level less than 10% of the groundwater reference value. The department also notified the registrant and conferred with the Illinois Department of Public Health, which agreed that no further action was necessary.

## Future Monitoring

If a compound-specific pesticide management plan is eventually required as a condition of continued product registration and use, the monitoring program will primarily consist of the IDA statewide monitoring well network and the

pesticide subnetwork of the IEPA community well (CWS) network. These two networks should provide the state with an initial, appropriate and accurate view of the pesticide occurrence in groundwater. If pesticides are present at concentrations greater than 10% of the groundwater reference value (or the detection limit if 10% of the reference value is less than the detection limit), additional well installations or other sampling programs may be necessary to determine the extent and severity of contamination. The department intends to continue to follow the sampling and analysis plan laid out in the generic management plan and the quality assurance project plan for the foreseeable future. If current trends in the occurrence of pesticides continue, some adjustments to the sampling plan may be considered.

## Summary

The Federal Government and the state of Illinois have been concerned with the protection of our groundwater resources for decades. The U.S. EPA has increased its focus on the issue of pesticides in groundwater since 1984 and has proposed strong state roles in the regulation of pesticide use. Although the federal approach has never become officially codified in regulation, the U.S. EPA has urged states to be proactive and voluntarily develop generic plans. States have responded in a very positive way and have developed generic pesticide management plans that attempt to customize pesticide regulation to specific groundwater issues present in their respective states. Illinois also has responded positively. It has developed and implemented a generic PMP with which the U.S. EPA has concurred. The Illinois Department of Agriculture remains dedicated to both ensuring the protection of the environment and allowing for the judicious and safe use of pesticides. The development and continued implementation of the state's generic PMP is one component of the department's overall program to meet these important goals.

## References


Goetsch, W.D., T. J. Bicki, and D.P. McKenna. 1992. Statewide survey for agricultural chemicals in rural, private water-supply wells in Illinois. Illinois Department of Agriculture, Springfield, IL.

Illinois Department of Agriculture. 2000. Illinois generic management plan for pesticides in groundwater. Springfield, IL.

Keefer, D.A. 1995a. Potential for agricultural chemical contamination of aquifers in Illinois: 1995 Revision. Illinois State Geological Survey Environmental Geology 148: 1–28.

Mehnert, E., D.A. Keefer, W.S. Dey, H.A. Wehrmann, S.D. Wilson, C. Ray, University of Hawaii. June 29, 2001. Illinois statewide monitoring well network for pesticides in shallow groundwater-network development and initial sampling results. Draft final contract report.

Schock, S.C., E. Mehnert, M.E. Caughey, G.B. Dreher, W.S. Dey, S. Wilson, C. Ray, S.F.J. Chou, J. Valkenburg, J.M. Gosar, J.R. Karny, M.L. Barnhardt, W.F. Black, M.R. Brown, and V.J. Garcia. 1992. Pilot study: agricultural chemicals in rural, private wells in Illinois. Illinois State Geological Survey and Illinois State Water Survey Cooperative Groundwater Report 14: 1–80.

U.S. EPA. December 1987. Agricultural chemicals in ground water: proposed pesticide strategy. Washington, DC.

U.S. EPA. July 1991. Protecting the nation's ground water: EPA's strategy for the 1990s. 21Z-1020. Washington, DC.

# Developing Nutrient Standards for Illinois

*George F. Czapar*

## Introduction

The United States Environmental Protection Agency (U.S. EPA) estimates that one-half of the surface water surveyed in this country does not adequately support aquatic life because of excess nutrients (U.S. EPA 1998). In 2001, the U.S. EPA published water quality criteria recommendations for total phosphorus (TP), total nitrogen (TN), chlorophyll a, and turbidity (U.S. EPA 2001). The nutrient criteria recommendations were developed with the goal of reducing and preventing eutrophication on a national scale.

Water quality criteria were developed for 14 different ecoregions in the United States. In Illinois, the northern two-thirds of the state is mainly in Ecoregion 6, whereas the southern one-third of Illinois is in Ecoregion 9. The recommended TP and TN annual concentrations for rivers and streams in Ecoregion 6 are 76.25 and 2.18 mg/l, respectively. In Ecoregion 9, the proposed TP value is 36.56 µg/l, whereas the average TN concentration is 0.69 mg/l.

These nutrient criteria were presented as recommendations, and each state was requested to develop a specific plan to outline how and when they intend to adopt nutrient criteria into their water quality standards. The Illinois EPA (IEPA) is responsible for developing this plan and suggested that the current U.S. EPA criteria may not be appropriate for Illinois surface water.

A report commissioned by the Illinois Association of Wastewater Agencies (IAWA), documented that the cost of adopting these standards would be very high. The IAWA estimated that construction costs to provide nutrient removal for the 814 municipal wastewater treatment plants would exceed $5.3 billion (Zenz 2003). They also estimated that increased annual operation and maintenance costs to remove TN and TP would be approximately $500 million per year.

The Illinois EPA has collected extensive water quality data over the past 30 years and has published a comprehensive summary of the numerous water monitoring programs that will be conducted through 2006 (IEPA 2002). One current challenge, however, is to better understand the relationship between nutrients and dissolved oxygen, and the ultimate effect on aquatic life.

## Strategic Research Initiative

The State of Illinois has funded research through the Illinois Council on Food and Agricultural Research (C-FAR) to examine the impact of nutrients on water quality. The goals of the Strategic Research Initiative (SRI) in Water Quality are 1) to help develop the scientific basis for nutrient standards in the surface waters of Illinois, and 2) to assist in the appropriate development and implementation of total maximum daily loads (TMDLs).

As part of the SRI, an advisory team from the Illinois EPA and the Illinois Department of Agriculture identified research needs, developed the request for proposals, and evaluated and selected projects. The final projects that were selected included scientists from the University of Illinois, Illinois State University, Southern Illinois University, the Illinois State Water Survey, and the Illinois Natural History Survey.

The SRI is organized into four research teams, each with a slightly different focus. Project components include a detailed analysis of existing Illinois EPA data to look for relationships between nutrients and biotic response in Illinois streams. In addition to analyzing historical data sets, they also are conducting intensive sampling upstream and downstream of a new sewage treatment plant.

A second group is exploring the seasonal dynamics of nutrients, algae, and dissolved oxygen. They are documenting annual patterns of algal biomass and dissolved nutrient concentrations with an emphasis on conditions during high flow events.

A third group is conducting statewide sampling at 142 sites from a variety of stream and land use types that receive agricultural and urban runoff, and wastewater effluents.

Sampling is conducted during high flow conditions and again during low flow conditions. In addition, 14 sites are being intensively sampled for numerous water quality parameters, including continuous measurement of dissolved oxygen.

The fourth group is focusing on sediment and phosphorus availability in Illinois streams. A principal outcome of this research will be to more clearly define the relationship between eutrophication and total phosphorus by determining what fraction of total phosphorus is potentially bioavailable. They also are characterizing how bioavailability varies with flow, stream order within a watershed, and between suspended and bed sediments.

Because standards need to consider all sources of nutrients, the SRI is collaborating with municipalities, including the Metropolitan Water Reclamation District of Greater Chicago and the Bloomington-Normal Water Reclamation District. All have a goal of protecting water from nutrient overenrichment without pursuing standards that are overly restrictive or unachievable.

As more results of the Water Quality SRI become available, they will contribute to the understanding of a complex natural system. Once the Illinois EPA develops a package of nutrient related water quality standards, it is the responsibility of the Illinois Pollution Control Board (IPCB) to make the final decision concerning adoption of standards (IPCB 2004).

## References


[IEPA] Illinois Environmental Protection Agency. 2002. Water Monitoring Strategy, 2002–2006. http://www.epa.state.il.us/water/water-quality/monitoring-strategy/index.html.

[IPCB] Illinois Pollution Control Board. 2004. http://www.ipcb.state.il.us/.

[U.S. EPA] United States Environmental Protection Agency. 1998. National strategy for the development of regional nutrient criteria. http://www.epa.gov/waterscience/standards/nutsi.html.

[U.S. EPA] United States Environmental Protection Agency. 2001. Water quality criteria—nutrients. http://epa.gov/waterscience/standards/nutrient.html.

Zenz, D.R. 2003. Technical feasibility and cost to meet nutrient standards in the state of Illinois. http://www.cte-eng.com/img/uploaded/pdfs/Illinois.pdf.

# The Conservation Security Program (CSP) and Cropland Nutrient Management Eligibility

*Dave Brandt*

The Conservation Security Program (CSP) is a voluntary conservation program that supports ongoing stewardship of private agricultural lands by providing payments for maintaining and enhancing natural resources. CSP identifies and rewards those farmers and ranchers who are meeting the highest standards of conservation and environmental management on their operations. CSP provides financial and technical assistance to promote the conservation and improvement of soil, water, air, energy, plant and animal life, and other conservation purposes on tribal and private working lands. Working lands include cropland, grassland, prairie land, improved pasture, and rangeland, as well as forested land that is an incidental part of an agriculture operation. CSP is sequentially available in all 50 States, the Caribbean area and the Pacific Basin area. The program provides equitable access to benefits to all producers, regardless of size of operation, crops produced, or geographic location. The Farm Security and Rural Investment Act of 2002 (2002 Farm Bill) (Publ. L. 107-171) amended the Food Security Act of 1985 to authorize the program. CSP is administered by USDA's Natural Resources Conservation Service (NRCS).

## How CSP Works

1. The CSP sign-up will be offered in selected watersheds across the nation.
2. Producers complete a self-assessment, including description of conservation activities on their operations, to help determine eligibility for CSP at this time.
3. Eligible producers in the selected watersheds submit an application at their local NRCS office.
4. Based on the application, description of conservation activities, and a follow-up interview, NRCS determines in which program tier and enrollment category the applicant may participate.

## Eligibility

The producer and the producer's operation first must meet the basic eligibility criteria:

- The land must be privately owned or tribal land and the majority of the land must be located within one of the selected watersheds.
- The applicant must be in compliance with highly erodible and wetland provisions of the Food Security Act of 1985, have an active interest in the agricultural operation, and have control of the land for the life of the contract.
- The applicant must share in the risk of producing any crop or livestock and be titled to a share in the crop or livestock marketed from the operation.

All applicants must meet the following minimum tier eligibility and contract requirements, plus any additional requirements in the sign-up announcement:

- For tier I, the producer must have addressed water quality and soil quality to the NRCS Field Office Technical Guide (FOTG) standards on part of the agricultural operation prior to acceptance.
- For tier II, the producer must have addressed water quality and soil quality to the FOTG standards on the entire

# Economic Benefits of Conservation Drainage

*Richard Cooke*

The passage of the 1850 Federal Swampland Act facilitated the drainage of thousands of acres of Illinois land, producing some of the most fertile cropland in the world. Some 10 million acres, about 35% of the total agricultural area in the state, is tiled. These drainage systems have a significant effect on the hydrology and water quality of the watersheds in which they occur. There is a strong correlation between improved drainage and elevated nutrient transport from cropped land.

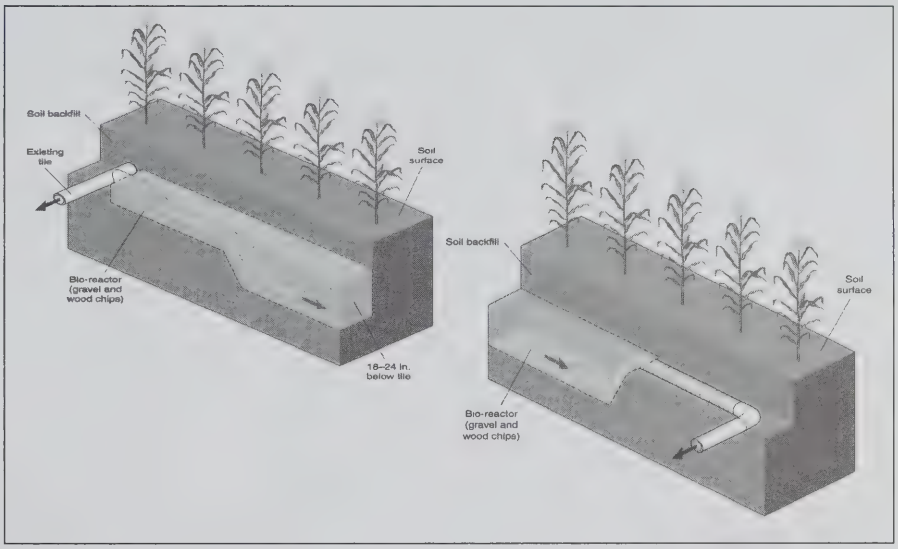



**Figure 1.** Schematic diagram of edge-of-field subsurface bioreactor.

Conservation drainage is the incorporation of environmentally friendly practices and structures into existing drainage infrastructure. These practices lead to the optimization of drainage practices for water quality objectives. In light of the importance of drainage to agriculture in the state, conservation drainage practices (CDPs) should reduce nutrient transport from drained land without adversely affecting drainage performance or crop production. The practices mentioned below satisfy this criterion.

## Bioreactors

Bioreactors are essentially subsurface trenches filled with a carbon source, mainly wood chips, through which water is allowed to flow just before leaving the drain to enter a surface water body (Figure 1). The carbon source in the trench serves as a substrate for bacteria that break down the nitrate through denitrification or other biochemical processes.

Bioreactors provide many advantages:

- They use proven technology.
- They require no modification of current practices.
- No land needs to be taken out of production.
- There is no decrease in drainage effectiveness
- They require little or no maintenance.
- They last for up to 20 years.

To ensure that there is no decrease in drainage effectiveness, water is allowed to bypass the system when the tile flow rate exceeds the flow capacity of the bioreactor. Typically, only 20–30% of the annual tile flow

**Figure 2.** Automated DWM structure on display.

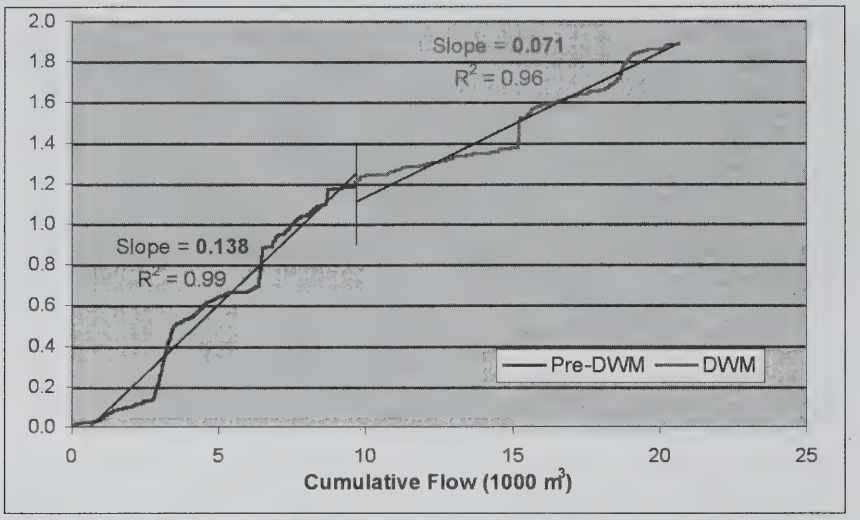



**Figure 3.** Phosphorus transport from a drainage system before and after the implementation of DWM.

passes through the bioreactor and is treated. Most of the flow bypasses the bioreactor during high-flow events.

Bioreactors have no adverse effects on production. They are designed so that they do not restrict drainage. Unlike other edge-of-field practices, they do not necessitate taking land out of production. They are also very cost-effective. However, there is no financial incentive for a producer to install one of these systems. Like other conservation practices, such as wetlands and buffer strips, it is expected that as these systems are further developed they will be considered worthy of public funding.

## Drainage Water Management (DWM)

In drainage water management (Figure 2), a control structure is placed at the outlet of a tile system to control the level of the water table in the soil. This practice can be used to raise the water level after harvest, thereby reducing nitrate loading from tile effluent, or to retain water in the soil during the growing season. The normal mode of operation in Illinois is to set the water table control height to within 6 inches of the soil surface on November 1 and to lower the control height to the level of the tile on March 15. Thus, water is held back in the field during the fallow period. In experiments in Illinois, reductions of up to 46.6 and 82.5% were measured for nitrate and phosphate, respectively.

Analysis of phosphorus data is complicated by the fact that there are few events in which inordinately large amounts of phosphorus are transported through the drains. It is surmised that these events result from preferential flow, and experiments to further explain this phenomenon have been initiated (Figure 3). The dominant mechanism for nitrate reduction is not denitrification, but is the reduction of flow volumes that result from implementing drainage water management (Figure 4).

Existing drainage systems can be retrofitted for drainage water management by installing control structures at a cost of $20–40 per acre. For new systems, additional costs are incurred by laying out the drainage systems to optimize the benefits of drainage water management.

In Illinois, drainage systems are normally laid out to minimize the cost of installation. However, such installations do not necessarily maximize the benefits of drainage water management. Two possible drainage systems that could be installed on the same field are shown in Figure 5. In all likelihood, this lower cost system would be the one selected for installation. In this instance, based on average installations costs, the difference in cost is $75/acre.

Drainage water management systems can be managed so that they store water during the growing season (Figure 6). This stored water can result in increased yields. One relationship between the additional cost of a drainage water management system and the corresponding breakeven income is shown in Figure 7. A system that costs $100/acre for example, has a break-even income of $7.05. Thus, it does not take a large yield increase to pay for the installation of a drainage water management system.

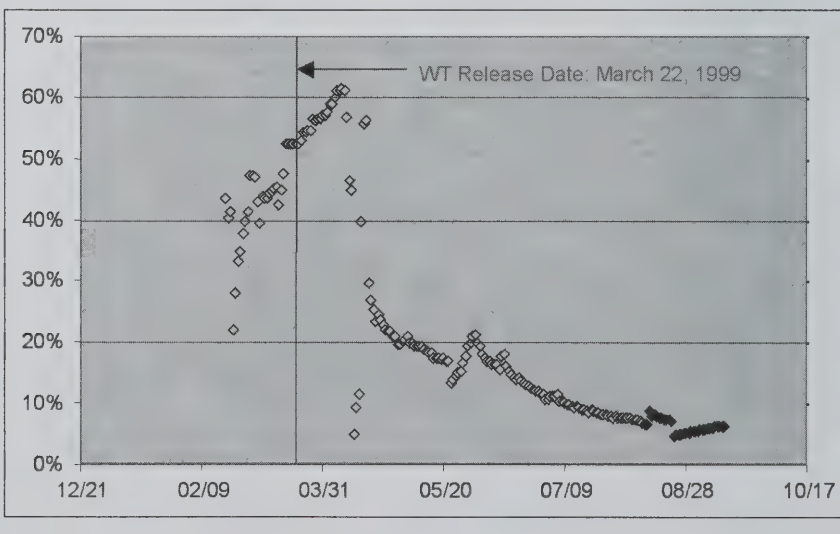



**Figure 4.** Nitrate reduction curve for a field under DWM compared with a similar field under free drainage.

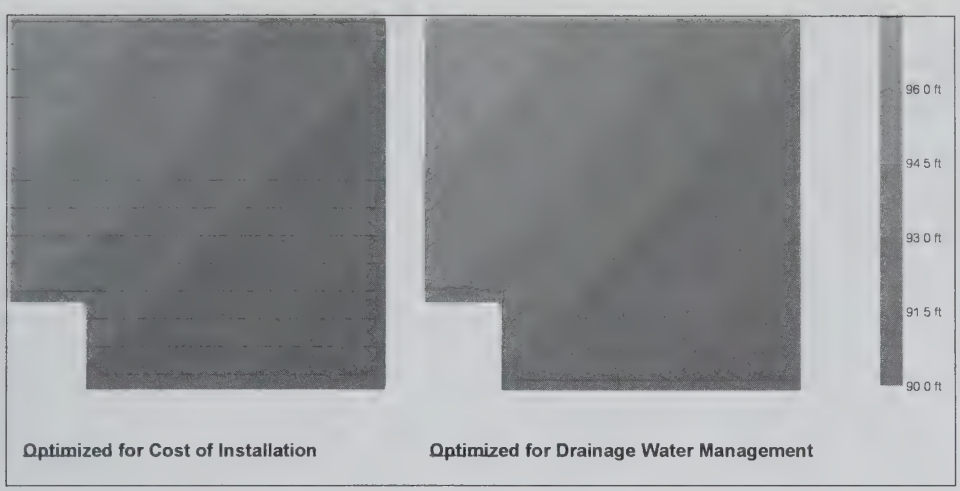



**Figure 5.** Effect of design objective on drainage system layout.

between spacing and average installation cost is shown in Figure 10. Also shown is the relationship between computer-simulated yield from a silt loam and spacing, by using 30 years of weather data from Urbana. Whereas the yield ratio varies with soil type and location, and the cost ratio varies with the contractor, the general form of the curves are representative of what can be expected in Illinois. Note that there is a threshold spacing beyond which no yield benefits can be obtained by putting the tiles closer together.

## Depth/Spacing Relationships

Originally, tile systems in Illinois were designed for the sole purpose of quickly removing excess water from the plant root zone to prevent wet stress and to improve crop yields. Drainage intensity is expressed as the drainage coefficient, the depth of water to be drained to lower a water table, initially at the soil surface, by a foot in 24 hours. Different combinations of depth and spacing result in the same drainage coefficient (Figure 8), but they may be different in their water quality response.

Experiments are being conducted on several soil types to determine depth/spacing combinations that optimize productivity with minimum adverse water quality effects. Preliminary results, shown in Figure 9, seem to suggest that shallower tiles placed closer together are more suitable than deeper tiles placed farther apart.

For a specified drainage coefficient, shallower tiles are associated with narrower spacing and thus drainage cost increases with decreasing tile depth. The relationship between spacing and average installation cost is shown in Figure 10. Also shown is the relationship between computer-simulated yield from a silt loam and spacing, by using 30 years of weather data from Urbana. Whereas the yield ratio varies with soil type and location, and the cost ratio varies with the contractor, the general form of the curves are representative of what can be expected in Illinois. Note that there is a threshold spacing beyond which no yield benefits can be obtained by putting the tiles closer together.

The yield and the cost curves can be used to determine the spacing that maximizes the rate of return on the investment in drainage. In this instance, the maximum rate of return was 17%, obtained at a spacing of 45 ft. If the spacing were reduced to 35 ft, so as to improve the quality of the drain effluent, the rate of return on the drainage investment would drop to 15%. This is still a substantial rate of return for the producer. Further benefits also would accrue from the improvement in downstream water quality.

## Conclusions

Conservation drainage practices are designed to provide water quality benefits. They are most likely to be adopted if they do not adversely affect profits. Some practices can be managed to provide production benefits. If these benefits exceed the costs, then there is economic incentive to imple-

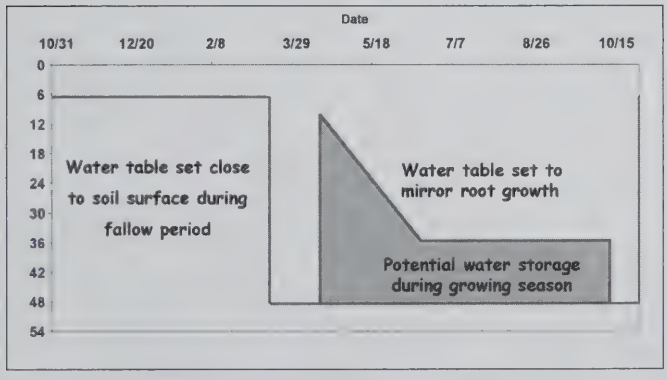



**Figure 6.** Water table settings required to operate drainage water management systems for both water quality and production benefits.

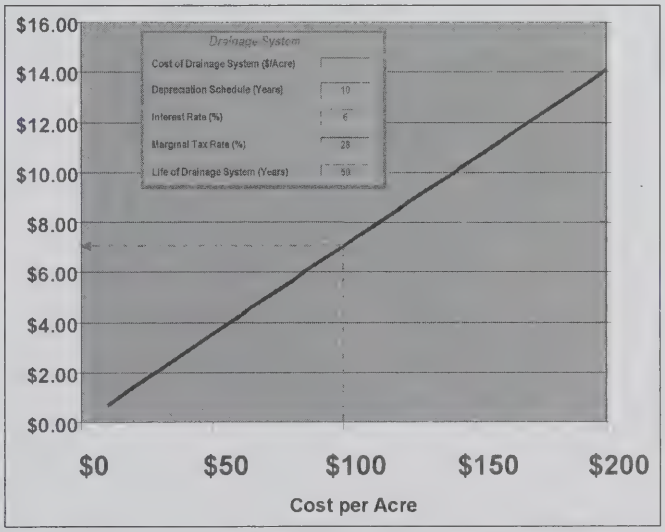



**Figure 7.** Relationship between cost and break-even income for a drainage water management system.

ment these practices. Other practices only provide benefits to the society at large, and it is not unreasonable to expect that they should be funded through grants or cost share programs.

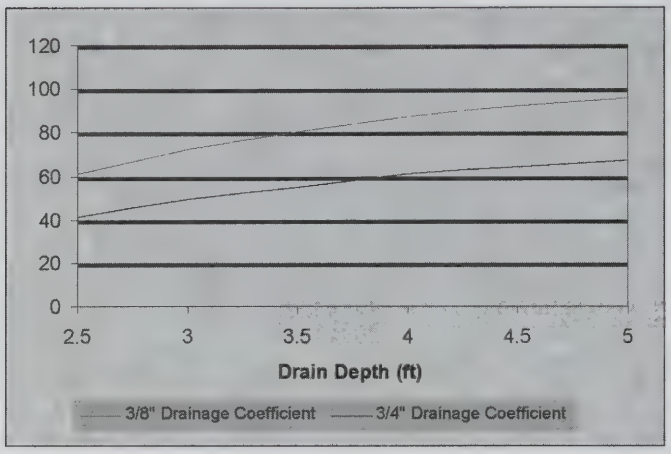



**Figure 8.** Drainage coefficient as a function of depth and spacing for Drummer Silty Clay Loam.

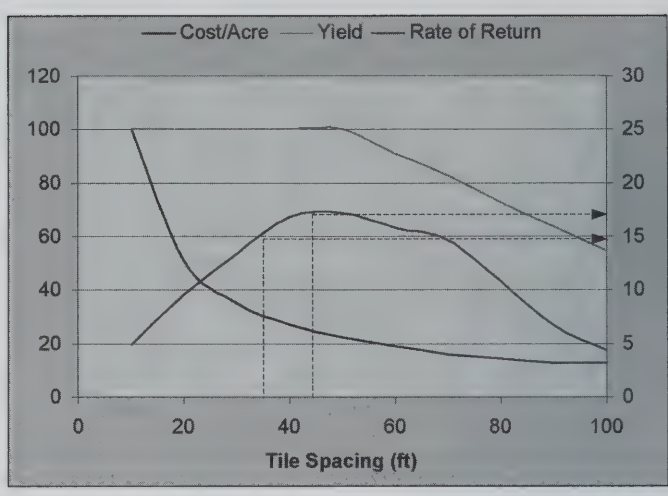



**Figure 10.** Simulated tile spacing/cost/yield relationship.

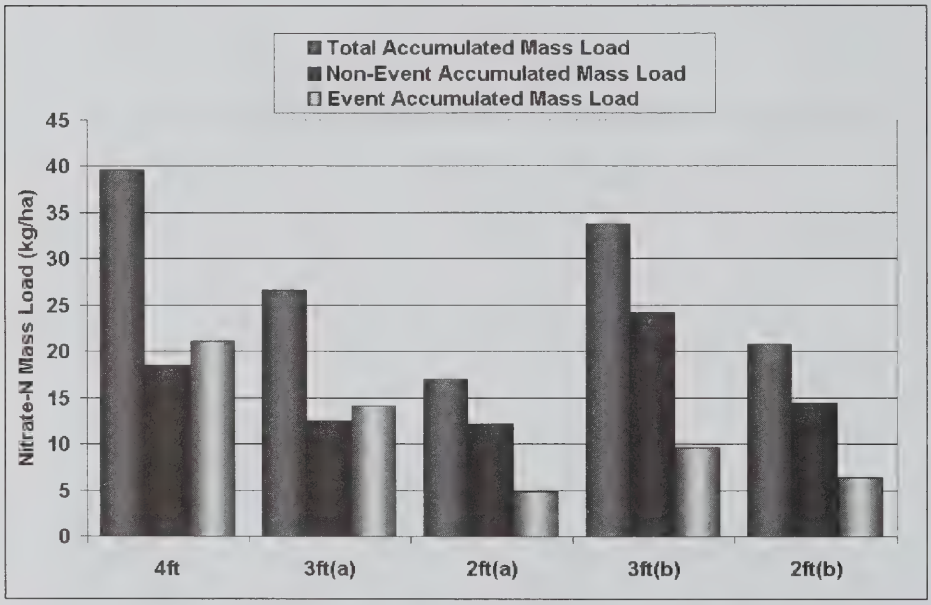
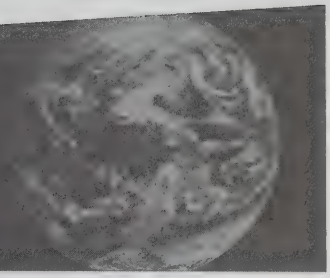



**Figure 9.** Nitrate loss at various drain depths in a depth/spacing experiment.

# Troubleshooting Pest Management Challenges in Field Crops



*Robert Bellm, Dave Feltes, and Matt Montgomery*

Crop diagnostic troubleshooting requires the use of inductive and deductive reasoning skills, combined with a sound technical background in pest management, crop physiology, and soil fertility. Usually, the injury symptoms we observe in the field are not caused by a single factor alone, but instead by an interaction of several factors. To make things even more confusing, different crop problems can cause very similar symptoms. Regardless, only the most careful questions and observations will lead to the correct answer.

New technological advances aid the diagnostic process. Digital cameras, hand-held computers equipped with global positioning system (GPS) receivers, and field mapping software enable us to gather, store, and archive information as never before possible. Cellular telephones, satellite uplinks, and Web-based communications systems enable us to send this information to others, and solicit diagnostic advice from experts around the world within just a matter of minutes. The cost of this technology is now affordable for any agronomic professional.

Technology offers many benefits, but it cannot be used as a crutch in place of learned diagnostic skills. The consultant still needs to know what questions to ask the client, what samples to collect and how to preserve them, and what pictures to take that will aid the diagnosis. Digital cameras and are wonderful tools, but an out of focus image or poor picture detail is useless. Let's face it, nothing beats being physically in the field and having the sample actually in your hand.

The most powerful diagnostic tool at your disposal is an open mind. In the rush of looking at fields, it is easy to assume that the cause of today's problem is the same as yesterday's, because the symptoms look similar. When you find yourself anticipating the diagnosis before you even get to the field, it is time to slow down a bit. Remember that biological systems contain a lot of variability and don't always allow for nice, obvious answers.

# Foliar Fungicide Basics for Field Crops

*Bruce E. Paulsrud and Dean Malvick*

## Introduction

Foliar fungicides are not currently widely used in Illinois field crops, but they are an important disease management tactic that may become more important in the future in some challenging disease management situations. Numerous factors must be understood to get maximum value from fungicide applications, including limitations of fungicides, what they do and how they work, reasons they may fail, ways to enhance their performance, and steps to take to avoid the development of fungicide-resistant fungal populations.

## Should a Fungicide be Used?

Fungicide applications should be preceded by accurate diagnosis of the disease to be managed and knowledge of the disease cycle of the pathogen being targeted. This information will not only help in making the decision of whether fungicides should be applied but also aid in choosing the proper fungicide and the proper timing for application. In addition, disease resistance of the hybrid or cultivar, weather conditions before and after the possible application date, and stage of crop growth and development must be considered. This information is critical for maximizing the likelihood that a fungicide application will be profitable.

Because many foliar diseases are initiated deep within the crop canopy, it is important to understand the limitations of the application equipment and fungicides used to manage diseases. Often, the application equipment must deliver the fungicide to the interior of the canopy. Application equipment and spray deposition issues are discussed elsewhere in this proceedings.

## Selecting a Fungicide

There are many different foliar fungicides available in the field crop market (Table 1) and more may be available in the future. As alluded to above, there are many factors to consider when deciding which fungicide to use. Product cost and efficacy are the primary factors that influence this decision. However, even the most effective fungicide will perform poorly if the basic product characteristics are not understood. Table 1 provides a summary of basic fungicide characteristics such as mobility and relative resistance risks.

A variety of terms are used to describe the mobility and activity of fungicides. Examples include protective-contact, local penetrant, local systemic, systemic, translocated, eradicant, and curative. These terms are described in this section, along with the practical significance of each.

## Protective-Contact Fungicides

These products remain on the surface of the plant foliage to protect it from infection for some period of time, and they do not enter the plant tissue (Figure 1). Uniform spray coverage is vital. The length of protection depends on many factors. As with any pesticide, rainfall or irrigation within a few hours after application may wash away much of the pesticide and greatly reduce the protective value. Even after drying on the plant surface, residues continue to be eroded via rain, dew, vaporization, and sunlight, thus reducing the protection. Furthermore, as the plant tissues expand or are replaced, the new tissue is left unprotected. For these reasons, protective-contact fungicides need to be reapplied more often than systemic fungicides. The addition of a spreader-sticker adjuvant to the spray mix may help improve coverage and slow residue loss. Always carefully read both the fungicide and the adjuvant label to ensure that the proposed tank mix is legal and safe for the crop.

## Local Penetrant and Systemic Fungicides

These products are absorbed into the plant. Some are fairly mobile within the plant, whereas others are not. Local penetrant (sometimes called local systemic) fungicides are absorbed into the immediate area of application but are not translocated far from the site of uptake (Figure 2). They serve to prevent the development of disease at and near the site of absorption. Systemic fungicides are more mobile

than local penetrants. However, nearly all systemic fungicides move only upward in the plant. This upward movement is sometimes referred to as acropetal or apoplastic translocation (Figure 3). The terms *curative* and *eradicant* are occasionally used to further describe certain systemic and local penetrant fungicides. These terms indicate generally that a fungicide has the ability stop the progress of infections that may have occurred hours or a few days before the application. This "kick-back" or "reach-back" characteristic is useful when responding to infection episodes. However, these fungicides are generally most effective when they are applied before infection or just after infection begins.

## Fungicide Resistance

There are many reasons why a fungicide might fail to adequately control disease. Often, fungicides don't provide the expected control because they are applied too early, too late, too infrequently, at the wrong rate, or too inconsistently to get even coverage on the plants. However, for those times when you know that everything has been done correctly and the performance is poor, consider that you may be dealing with a fungicide-resistant pathogen population.

Where do fungicide-resistant fungal pathogens come from? One origin is via introduction of resistant types from another area, and the other is through genetic change in the pathogen population in a particular area. Genetic mutations can allow resistant fungi to occur at very low numbers within a fungal population. When a fungicide effectively controls the susceptible members of a species, only those that possess a resistance trait can survive and reproduce. It is important to remember that resistant populations start out in very small numbers. It may take years for you to notice resistant populations, and you may only perceive the problem as a poorer or shorter-than-expected duration of fungicide protection.

How do you know whether you are truly dealing with a fungicide-resistant pathogen population? Several criteria may be used to diagnose the problem:

**Table 1.** FRAC Group, relative resistance risk, and mobility for example foliar fungicides. Not all of these products are labeled for use on field crops in Illinois.

| FRAC Group code and name [target site of action] | Common name | Trade name(s) | Relative resistance risk[1] | Mobility |
|---|---|---|---|---|
| **1.** Methyl benzimidazole carbamates [mitosis: ß-tubuline assembly] | Thiophanate-methyl | Topsin-M | High | Systemic (upward) |
| **3.** Demethylation inhibitors (DMI) [C14-demethylation in sterol biosynthesis] | Myclobutanil | Laredo | Medium | Systemic (upward) |
| | Propiconazole | Bumper<br>PropiMax<br>in Quilt<br>in Stratego<br>Tilt | Medium | Systemic (upward) |
| | Tebuconazole | Folicur | Medium | Systemic (upward) |
| | Tetraconazole | Domark | Medium | Systemic (upward) |
| **7.** Carboximides [complex II in fungal respiration (succinate-dehydrogenase)] | Boscalid | Endura | Medium | Systemic (upward) |
| **11.** Quinone outside inhibitors (QoI) [complex III of fungal respiration: ubiquinol oxidase, Qo site in mitochondria] | Azoxystrobin | Quadris<br>in Quilt | High | Systemic (upward) |
| | Pyraclostrobin | Headline | High | Local penetrant |
| | Trifloxystrobin | in Stratego | High | Local penetrant |
| **M3.** [multisite contact activity] | Mancozeb | Dithane<br>Manzate | Low | Contact-protective |
| **M5.** [multisite contact activity] | Chlorothalonil | Bravo<br>Echo | Low | Contact-protective |

[1] Cross resistance should be anticipated within numbered FRAC Groups.

** Fungicide labels change frequently; check product labels and consult with manufacturers for current registration and crop use information.

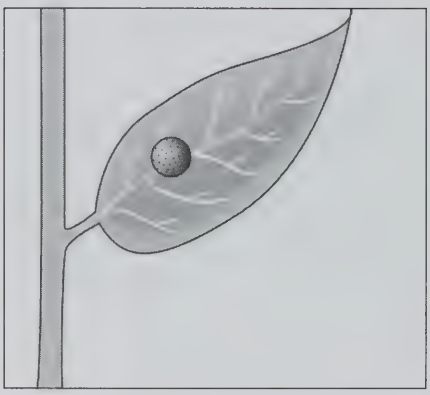


**Figure 1.** Protective contact fungicides do not enter the plant.

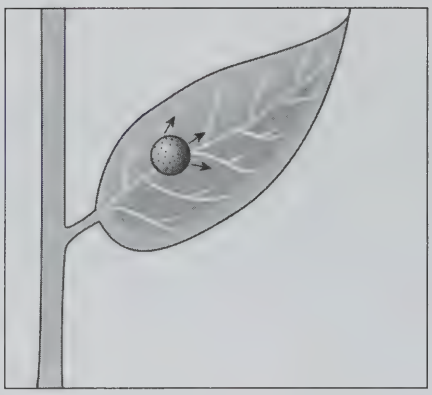


**Figure 2.** Local penetrant fungicides are absorbed but remain close to the site of uptake.

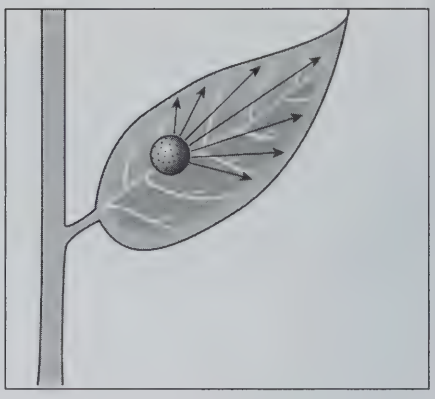


**Figure 3.** Nearly all systemic fungicides only move upward in the plant (acropetal translocation).

- The disease was controlled effectively with this fungicide in the past.
- All other causes of fungicide failure have been eliminated (timing, frequency, canopy penetration, environmental, or misapplication problems, and so on).
- Other diseases on the fungicide label (besides the one in question) were controlled effectively.
- The site has a history of continuous use of the same fungicide or other fungicides within the same FRAC Group.

If you answer "yes" to several or all of these criteria, you should suspect resistance; review your observations with a plant pathologist and the fungicide manufacturer representative.

## Resistance Terminology

When discussing fungicide resistance, the terms can sometimes be confusing. The following are the key terms you should understand.

*FRAC*: Fungicide Resistance Action Committee, an international, industry-based committee that issues guidance and antiresistance strategies for different fungicide groups. FRAC organized the existing fungicide active ingredients into target site groups and gave each group a specific code number. For example, FRAC Group 3 includes the well-known DMI fungicides. FRAC Group codes are beginning to be printed on some fungicide labels, which will help in preparing resistance management plans.

*Resistance*: Fungicides have low or no ability to control a fungus that should be controlled with that fungicide. Because the term "resistance" may be interpreted as "absolute resistance" or may be confused with host plant resistance, plant pathologists sometimes use the terms "insensitivity" or "tolerance" instead of resistance. However, some experts argue that the term "insensitivity" should be reserved for describing a fungus that is not inherently controlled by a fungicide (e.g., DMI fungicides never did control *Pythium* or *Phytophthora*; the pathogens did not change). Regardless of the term used, be cautious when interpreting reports of fungicide resistance. Just because a pathogen population is deemed resistant to a fungicide, it does not necessarily mean it will completely fail to control the pathogen. Like host plant resistance, there are degrees of fungicide resistance.

*Cross-resistance*: Where pathogens are resistant to different fungicides, especially within the same FRAC Group. For example, you would suspect cross-resistance if you switched from azoxystrobin to trifloxystrobin and a strobilurin-resistant pathogen population was not controlled. Both of these fungicides are strobilurins and belong to FRAC Group 11.

*Multiple resistance*: Where pathogens are resistant to fungicides from different FRAC Groups. For example, you would suspect multiple resistance if you treated the previously mentioned strobilurin-resistant population with propiconazole (a FRAC Group 3 fungicide) and found that you still could not control the disease.

## Being Proactive About Fungicide Resistance

Specific recommendations for reducing the potential for development of fungicide resistance include the following:

- The use of fungicides should be integrated into an overall disease and pest management program that includes appropriate cultural practices, host plant resistance, and scouting.
- Apply fungicides when disease first occurs and when predictive models suggest disease is likely to occur.
- Do not use a lower than recommended rate or rely upon curative or late applications.

- Avoid using an active ingredient (or members of the same FRAC Group; Table 1) more than once per season. For example, there are a number of fungicides with a strobilurin group as the active ingredient, and they all have the same site of action (FRAC Group 11). Thus, exclusive use of different active ingredients within the same FRAC Group is a poor rotation strategy that may promote development of resistant pathogens. If multiple applications are necessary, alternate or tank mix effective active ingredients from different FRAC Groups.
- Monitor the efficacy of all fungicides used and record other factors that may influence fungicide performance and disease development.

## Conclusion

By understanding specific diseases, pathogens, and fungicides and executing a sound fungicide use and resistance management plan, you can increase profitability of fungicide use and reduce the chances that fungicide-resistant pathogens will become a problem.

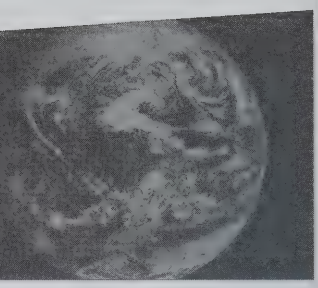
## References

Brent, Keith, J. 1995. Fungicide resistance in crop pathogens: how can it be managed? Fungicide Resistance Action Committee. April 1995. http://www.frac.info/publications.html. Accessed October 2004.

FRAC Fungicide List 1 (arranged by FRAC Code). Fungicide Resistance Action Committee. http://www.frac.info/publications.html. Accessed October 2004.

Locke, Tom, et al. 2001. Fungicide resistance. Fungicide Resistance Action Group – UK. August 2001. http://www.pesticides.gov.uk/uploadedfiles/Web_Assets/RAGs/FRAG_UK_leaflet.pdf. Accessed October 2004.

# Secondary Insect Management



*Kevin Black and Murdick McLeod*

When the term "secondary insect pest" is mentioned among agricultural professionals, most have a good idea of what is meant. Ask these same individuals which insects belong in this group, however, and there can be significant differences. Among these differences are notable local applications of the "secondary insect" title. For example, to some individuals, wireworms are clearly secondary insects. For others, wireworm injury to crops occurs with great regularity and causes significant losses if unmanaged. Wireworms are then a secondary pest for one and a primary pest for another.

The crop also makes a difference. For the seed corn producer, the pest management program may be constructed around corn earworms or European corn borers, pests of high importance. For the field corn producer, occurrence of these pests may be infrequent or insignificant. In this example, the corn earworm is a primary pest for one crop, but becomes a secondary pest for another.

Secondary insect pest also has had different meanings over time. One meaning formerly referred to such insects as those that could increase in significance after management efforts against the "primary insect pest." In one application of this use, insecticide treatment for control of the primary pest "released" the secondary pest and essentially elevated the status and damage potential of the secondary pest.

Another common use of the term secondary insect is a catch-all. Under this use, most pest insects fall into the secondary insect pest category. Insects such as the corn rootworm, the "billion dollar bug," are seldom referred to as primary insect pests. This status is largely understood and not stated. Meanwhile, the white grub of the Japanese beetle retains its status as a secondary pest, even though dollar losses in individual fields may rival that of the corn rootworm.

For many secondary insects, the defining issue is frequency of occurrence or geographic distribution. Black cutworm can certainly be a major source of economic damage in fields where infestations occur, but the total number of fields affected over a wide geography is typically low. The discriminating egg-laying habits of the black cutworm also ensure that not every field is blessed with its presence. Furthermore, if timing of southern storm fronts fails to coincide with moth flights, few cornfields end up being infested. These factors can result in assignment of the secondary insect label to the black cutworm, yet not everyone agrees that the black cutworm is a secondary pest.

The grape colaspis is another insect that can be maddening in its damage potential, infrequency of occurrence, and difficulty in predicting and managing infestations. Grape colaspis is a secondary insect by virtue of relatively low frequency of economic infestations and total number of affected fields, but on some farms, it is a major pest. This brings up another issue. Secondary insect pests often have the capacity to cause significant damage but, if the damage is not somewhat spectacular, their activity is often overlooked or underappreciated.

Finally, some secondary insects are so called because of total dollars spent on management, or on attributable dollar losses. Accurate dollar loss figures are difficult to find for many insect pests, but when comparisons of overall economic losses are considered, there are usually large magnitudes of difference between dollar losses from primary and secondary insect pests. So, across the Corn Belt, the corn rootworm may, indeed, be a billion dollar pest, whereas losses from corn leaf aphids (or other secondary insect pests) may be measured in mere hundreds of thousands, or millions of dollars.

The dollars lost or spent on management of insect pests creates an associated problem with research dollars. The most costly insect pests tend to generate the most research dollars. Secondary insects qualify for significantly less research effort. In addition, the more sporadic occurrence and reduced predictability of secondary insects means that fewer researchers or graduate students are willing to commit years of their lives to study of these insects. It used to be said that, if you want to cause a crash in a secondary insect population, build a research project around it. There

is a frustrating lack of information available concerning many secondary insects.

Every crop has its principle and secondary insect pests. Following is an abbreviated list of insects usually regarded as secondary pests of major Illinois crops.

### *Field Corn*

- Armyworms (including fall armyworm)
- Billbug
- Black cutworm (?)
- Chinch bug
- Corn earworm
- Corn leaf aphid
- Flea beetle
- Grape colaspis
- Hop vine borer
- Japanese beetles
- Seedcorn beetles
- Seedcorn maggot
- Southern corn leaf beetle
- Stalk borers
- Stink bugs, brown and onespotted
- Thrips
- White grubs
- Wireworm (?)
- Yellow woollybear caterpillars

### *Soybean*

- Blister beetle
- Corn earworm (podworm)
- Dectes stem borer
- Grape colaspis
- Grasshoppers
- Green cloverworm
- Japanese beetle
- Potato leafhopper
- Seedcorn maggot
- Soybean aphid (?)
- Stink bugs
- Thistle caterpillar
- White grubs
- Wireworm
- Yellow woollybear caterpillar

### *Wheat*

- Aphid complex
- Armyworms
- Cereal leaf beetle
- Hessian fly (?)
- Wheat stem maggot
- Wheat stem sawfly

### *Alfalfa*

- Alfalfa plant bugs (including lygus bugs)
- Clover leaf weevil
- Clover root curculio
- Fall armyworm
- Meadow spittlebugs
- Alfalfa blotch leafminer

It would be very easy to argue that several of the insects, listed above [with (?)], are really major, or primary, crop pest insects. For insects, such as the soybean aphid, it is likely that we will have few years in which we have outbreaks like the outbreak of 2003. In this case, it is frequency of occurrence and overall geographic distribution that cause the insect to be demoted to a secondary pest, even though we have witnessed its impressive potential to reduce soybean yield.

Insects, such as the green cloverworm in soybean or the Hessian fly in wheat once were considered major pests, but biological control and host plant resistance, respectively, resulted in the change in status for these insects. The alfalfa weevil is another insect that once was so damaging that growing of alfalfa was reduced and nearly discontinued. Introduction of biological control agents to combat the alfalfa weevil resulted in fairly consistent annual reductions in alfalfa weevil damage, although severe damage still occurs with some frequency.

Armyworms in wheat or corn, and black cutworms in corn are two more insects that could easily be promoted to the major insect pest category, except for the limited frequency and distribution of damaging infestations. Southwestern corn borers also can occasionally be damaging in southern counties of Illinois, but the limited geography affected, frequent heavy winter mortality of larvae, plus increased use of corn carrying the *Bacillus thuringiensis* (Bt) corn borer resistance gene, helps keep southwestern corn borers in the secondary insect group.

Secondary insect pests present unique management challenges. Scouting procedures, damage thresholds, and practical management methods are well understood for insects such as black cutworm in corn. We are also rapidly increasing our knowledge of, and ability to manage, insects such as the soybean aphid. For many secondary insects, however, research is lacking and we simply do not have the knowledge level and experience necessary for effective management.

Accurate prediction is another shortcoming for many secondary insect pests. The sporadic nature of many of the insect populations makes it difficult to confidently predict problems. Furthermore, scouting for many secondary insect pests is inherently difficult. Insects, such as the grape

colaspis, are often noted only after much of the damage is done. Finally, management or control of secondary insect pests can be limited by scarcity of labeled insecticides, poor understanding of product efficacy, and inability to deliver insecticides as rescue treatments.

Some of the secondary insect pests are difficult to control through conventional means. This seems to be especially true of the soil-inhabiting pests. Recent introduction of new insecticide seed treatments has greatly impacted our ability to manage some of these difficult pests.

The principle goal of this specialized session is to present and discuss the following compiled information:

- Biological profiles and unique pest features of secondary insects
- Damage potential and economic losses from secondary insects
- Economics of secondary insect management
- Scouting and prediction of secondary insect damage
- Economic thresholds or action guidelines for secondary insects
- Biological and cultural management of secondary insects
- Summary evaluation of traditional insecticides for secondary insect control
- Control of secondary insects with insecticide seed treatments
- Tillage, soils and planting date influence on secondary insect problems

Focus is placed on secondary insects on the "most wanted list." These insects are the ones we have had to deal with the most in recent years or those for which we have received the most questions. We invite symposium participants to participate in discussion and contribute information from their own field experience in dealing with secondary insects. Where knowledge gaps are highlighted for specific pests, audience interaction is encouraged. By the end of the session, hopefully everyone will leave with greater knowledge about this interesting and challenging group of insects.

# Wheat Management for the 21st Century

*E. A. Adee and S. A. Ebelhar*

## Fall Management

### 1. *Variety selection*

Select varieties with proper disease resistance and agronomic qualities (including yield, test weight, winter hardiness, and lodging resistance).

Northern Illinois priorities: a) good winter hardiness, b) scab resistance, c) leaf disease resistance.

Southern Illinois priorities: a) leaf disease resistance, b) scab resistance, c) early harvest for early double-crop soybean planting.

Fields with a history of soilborne mosaic virus or spindle-streak mosaic virus need to have resistant varieties.

Select best yielding varieties that match your priorities. Typical yield ranges in variety trials are 20–30 bushels. Wheat performance trials from University of Illinois are a good source: http://vt.cropsci.uiuc.edu. Look for consistent performance across regions, years, or both.

### 2. *Rotation*

Wheat generally does better following soybean than corn. Adding wheat into a corn–soybean rotation has been shown to increase corn yields 10–12 bu/acre and soybean yields 5–6 bu/acre.

### 3. *Tillage*

Wheat yields are generally increased with tillage, but wheat no-tilled into soybean stubble yields very similar to wheat in tilled soil if planted on time. Tillage makes a bigger difference following corn.

### 4. *Fall fertility*

Apply at least 20 lb nitrogen (N), but no more than 40 lb to wheat in the fall. Days after planting (DAP, 18–46–0) is a good source of N if phosphorus (P) is needed. Apply P and potassium (K) as needed based on soil tests and proven yields. Include the P and K needs of double-crop soybean with wheat fertilization in the fall.

### 5. *Seed treatment*

Insecticide treatments may have less benefit for later planted wheat.

Fungicide treatments may be more beneficial for later planted wheat.

### 6. *Fall seeding*

As soon after the Hessian fly-free date as possible. Effects of aphids spreading barley yellow dwarf virus (BYDV) are reduced by planting after the fly-free date. Other diseases also may be held in check by planting after the fly-free date. In northern Illinois, wheat yields declined 0.7 bu/acre for every day planting is delayed. In southern Illinois, yield declines are less severe. Later planting dates have more adverse effects on yield if wheat is following corn or if no-tilled.

Optimum planting depth is 1 to 1.5 in.

Optimum seeding rate is 30–35 seed per square foot adjusted for germination. Increased seeding rates are justified when a) planting is delayed, b) no-tilling, and c) planting into corn residue.

### 7. *Fall weed control*

Fall competition from weeds should be eliminated by either tillage or use of burndown chemical if no-tilling.

Volunteer wheat can be a "green bridge" for diseases such as wheat streak mosaic virus; the wheat curl mite is the vector. The mites can be blown to the new wheat crop, infecting it with the virus. Kill the volunteer wheat before the new crop emerges.

### *8. Insect scouting*

The biggest concern with fall wheat is BYDV transmitted by aphids when conditions are right. This may be associated with late maturing corn, early planted wheat, or both. Scouting and controlling threshold aphid levels should be carefully considered through the end of November.

## Spring Management

### *9. Spring N management*

***Uniformly*** apply remainder of N before jointing for a total fall plus spring N of 70–90 lb on darker soils and 90–110 lb on low organic matter (forested) soils adjusting for yield potential and N credits. Apply 20 lb additional N to no-tilled fields.

Apply liquid N sources with dribble nozzles or dilute urea ammonium nitrate (UAN) to avoid leaf burn.

Spring split N rates can increase N efficiency but no big yield benefits have been observed over proper N timing management (single application at Feekes GS 5.0).

### *10. Spring weed control*

Scout for winter annuals shortly after green up and apply foliar herbicides, if necessary, before jointing. Herbicides may be applied with spring application of N, but leaf burn can be a problem.

### *11. Diseases/scab scouting*

Disease management in the spring centers on protection of the flag leaf if conditions are suitable for foliar diseases (i.e. leaf rust and Septoria) to develop. This is more critical before and at heading than towards the end of grain fill.

Monitor environmental conditions at blooming for conditions favorable for scab infection (heavy dew and rain for extended periods). Scab may be more likely in wheat following corn.

### *12. Fungicide management*

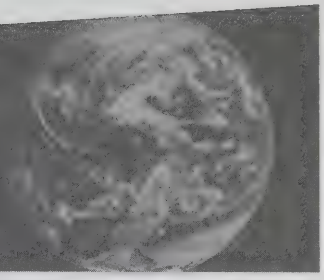
Treatment of wheat with fungicides should match potential for disease development as described above. Matching the right fungicide with the right disease and with the proper timing of application are critical. Off-label uses of fungicides are ***never*** appropriate.

Results from fungicide trials show there are some products effective in reducing scab.

### *13. Harvest management*

Timely harvest avoids loss in grain yield (shattering, birds) and quality (sprouting, lower test weights). Harvesting at higher moisture and drying in the bin can help avoid harvest losses and allow for earlier double-crop soybean planting, which can increase yields.

# Corn Nematodes: The Hidden Enemies



*Terry L. Niblack*

Because of the changes taking place in integrated pest management practices in corn production, we can expect corn nematode problems to increase. Some of those changes include insecticide chemistry, tillage, and fertilization rates, all of which impact the probability of nematode damage in corn.

Nematodes are the most frequently overlooked cause of corn disease. These tiny animals feed on corn roots and cause symptoms that could be blamed on many different kinds of stress. They also can intensify expression of specific symptoms due to nutrient deficiency, herbicide injury, and other causes.

There are three myths about corn nematodes that should be exploded right away.

- Myth 1 is that corn nematodes only occur in sandy soils. Not true! Damage in sandy soils is more likely to be spectacular—dead or dying plants in the center of a large oval of stunted plants—but damage does occur in heavier soils. It's usually misdiagnosed as nutrient deficiency or herbicide injury and it isn't necessarily obvious—until harvest, that is.
- Myth 2 is that corn nematode injury is rare. It isn't! And it's going to get worse over time. The major contributing factors are reduced tillage, use of genetically modified corn for insect control, and the changing chemistry of insecticide and nematicides.
- Myth 3 is that "corn nematode" means one particular kind of nematode. It doesn't! There are at least four major types of corn–parasitic nematodes that can seriously damage corn in Illinois.

The most important corn–parasitic nematodes in Illinois are lesion, needle, dagger, and lance.

- Lesion nematodes feed inside corn roots. Infected root systems have brown spots, or lesions, forming on a few to most of the individual roots. Heavily infected roots rot. Thus, lesion nematode injury, which occurs most frequently on heavier soils, is usually diagnosed as root rot, and the nematode cause is overlooked.
- Needle nematodes are devastating and, in high enough densities, can kill seedlings. The pictures you usually see of "corn nematode damage" are pictures of injury due to needle nematodes. Because these animals are large (as worms go), they are limited to sandy soils. In needle nematode-infested fields, grassy weed control is important because these nematodes can feed and maintain their populations on grassy weeds.
- Lance nematodes usually cause "hidden injury," that is, subtle damage that is very difficult to detect from looking at the plants. These nematodes can feed from either the inside or outside of corn roots and can predispose plants to other types of diseases.
- Dagger nematodes are some of the most common nematodes in corn nematode samples. Although they are large for nematodes, they are not limited to sandy soils and can cause damage in a wide range of soil types.

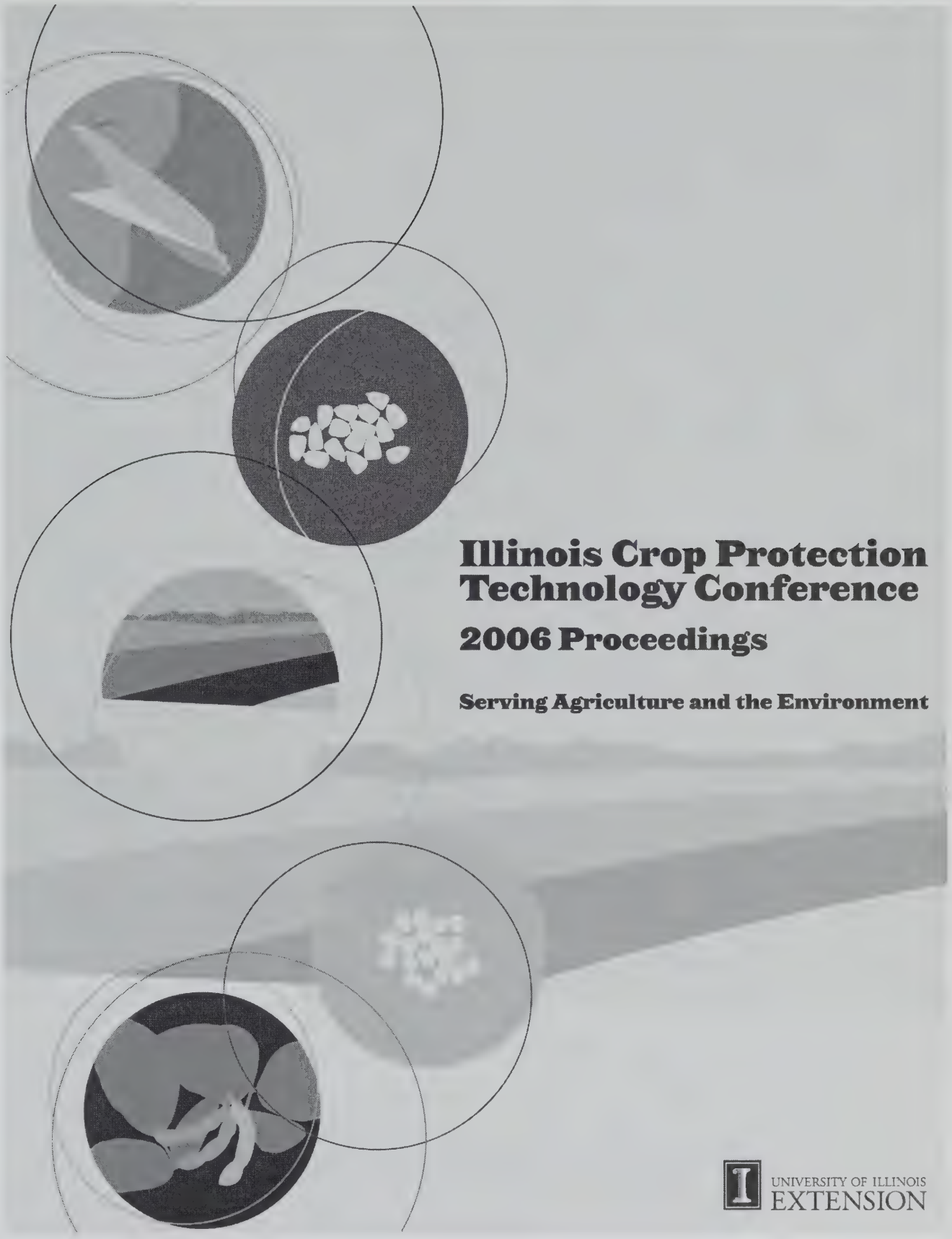
Control of corn–parasitic nematodes depends on proper diagnosis! Submit your corn samples to the Plant Clinic (see http://plantclinic.cropsci.uiuc.edu/) or a reliable private laboratory. Be on the lookout for increasing corn nematode damage and don't let nematodes remain the last thing on your corn production checklist!

# Illinois Crop Protection Technology Conference

## 2006 Proceedings

### Serving Agriculture and the Environment

UNIVERSITY OF ILLINOIS
EXTENSION



# Illinois Crop Protection Technology Conference

## 2006 Proceedings

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# Planning Committee

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# Illinois Crop Protection Technology Conference Program

## Wednesday Morning, January 4

**Opening Session** • Illini Union Rooms A, B, and C • *Todd Gleason, Moderator*

(1.5 CCA credits in Integrated Pest Management and 1 CCA credit in Crop Production)

| | |
|---|---|
| 9:00 AM | Welcome and Opening Remarks • *Mike Gray and Kevin Steffey* |
| 9:15 AM | The College of ACES in the 21st Century • *Robert Easter* |
| 9:30 AM | The First 10 Years of Transgenic Crops in North America: Fact, Figures, and Fiction • *Bruce Chassy* |
| 10:15–10:45 AM | Break • South Lounge |
| 10:45 AM | The Day After Yesterday • *Aaron Hager, Dean Malvick, Emerson Nafziger, and Kevin Steffey* |

2005 will be remembered in the annals of Illinois agriculture as a year during which environmental conditions and pest issues—both anticipated and realized—combined to test our crop production proficiencies. Crop production challenges generate both uncertainties and opportunities for solutions. Panel members will interact to address 2005, a year in review—What happened? What did we learn? How can we use what we learned for the future?

| | |
|---|---|
| 12:00–1:00 PM | Lunch • On your own |

## Wednesday Afternoon, January 4

***Symposia A, B, and C run concurrently from 1:00–2:45 PM.***

**Symposium A—Soil Fertility Strategies: Managing Future Changes and Challenges** • Ballroom • *Bob Nielsen, Moderator*

(1.5 CCA credits in Nutrient Management)

2006 promises to be a challenging year in the fertilizer industry. Understanding the dynamics of global supply, demand, and distribution, as well as regional and local fertility issues, will test even the most seasoned nutrient specialists. This symposium will provide an outlook on fertilizer supply and demand, a proactive look at nutrient strategies, and a preview of the upcoming changes in Illinois nitrogen rate recommendations.

| | |
|---|---|
| 1:00 PM | Generating N Recommendations from Data • *Emerson Nafziger* |
| 1:25 PM | Worldwide Nutrient Supply and Market Update • *Mark Nordwald* |
| 1:50 PM | Understanding N Loss Mechanisms and Improving N Use Efficiency • *Greg Schwab* |
| 2:15 PM | Questions and Answers |

**Symposium B—Glyphosate-resistant Weeds: Current Status, Potential Implications** • Rooms 314A and B • *George Czapar, Moderator*

(1.5 CCA credits in Integrated Pest Management)

The occurrence of glyphosate-resistant weed biotypes in the United States has increased since the commercialization of crop varieties and hybrids that allow for concomitant, in-crop applications of glyphosate. Some of the weed species first identified with glyphosate-resistant biotypes were not common to Illinois, but several recently identified glyphosate-resistant biotypes come from species that can be commonly found in Illinois corn and soybean production fields. This symposium will bring participants up-to-date on glyphosate-resistant weed biotypes, and provide discussion about how the occurrence of glyphosate-resistant weeds may affect weed management practices in the very near future.

| | |
|---|---|
| 1:00 PM | Glyphosate-resistant Weeds: A Global Perspective • *Ian Heap* |
| 1:20 PM | What the #%@& is Going on with Lambsquarters and Glyphosate? • *Mark Loux* |
| 1:40 PM | A Business Perspective on Weed Resistance • *Larry Weller* |
| 2:00 PM | The Illinois Outlook: Can it Happen Here? • *Aaron Hager* |
| 2:20 PM | Questions and Answers |

**Symposium C—Wrestling with Old, New and Persistent Management Challenges in Corn** • Illini Rooms A and B • *Mike Hellmer and Rodney Weinzierl, Moderators*

(1.5 CCA credits in Integrated Pest Management)

This symposium will begin with a current assessment of the western bean cutworm invasion into Illinois. The performance of soil insecticides, insecticidal seed treatments, and transgenic corn rootworm hybrids will be reviewed in light of increasing concerns over the variant western corn rootworm's geographic range expansion. Densities of an old insect nemesis, the European corn borer, have been declining throughout the Midwest. How

concerned should producers be with respect to this insect for next year and beyond? With projected energy, fertilizer, and other production costs escalating, which crop production system is most advantageous for 2006, continuous or rotated corn?

| | |
|---|---|
| 1:00 PM | Western Bean Cutworms Expand Their Range in 2005: Expectations for 2006 • *Kelly Cook* |
| 1:10 PM | Impact of YieldGard Rootworm on Corn Rootworm Control: A Proven Technology for Producers • *Ty Vaughn* |
| 1:30 PM | Transgenic Corn Rootworm Hybrids, Soil Insecticides, and Seed Treatments: Does Anything Work on the Variant Western Corn Rootworm? • *Mike Gray* |
| 1:50 PM | European Corn Borers: A Diminished Insect Threat From Now On? • *Rick Hellmich* |
| 2:10 PM | Corn and Soybean Rotations: Where To From Here? • *Gary Schnitkey* |
| 2:30 PM | Questions and Answers |
| 2:45–3:15 PM | Break • South Lounge |

***Symposia A, B, and C are repeated concurrently from 3:15–5:00 PM.***

**Symposium A (repeated)—Soil Fertility Strategies: Managing Future Changes and Challenges** • Ballroom

**Symposium B (repeated)—Glyphosate-resistant Weeds: Current Status, Potential Implications** • Rooms 314A and B

**Symposium C (repeated)—Wrestling with Old, New and Persistent Management Challenges in Corn** • Illini Rooms A and B

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| | |
|---|---|
| 5:00–6:30 PM | IFCA-Sponsored Mixer • Illini Union South Lounge |

This mixer is sponsored by the Illinois Fertilizer and Chemical Association. It is intended for everyone to meet with speakers, sponsors, and committee members in an informal atmosphere.

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## Thursday Morning, January 5

***Symposia D, E, and F run concurrently from 8:00–9:45 AM.***

**Symposium D—Will That New Sprayer Get "Rusty?"** • Illini Rooms A and B • *Robert Bellm and Kevin Black, Moderators*

(1.5 CCA credits in Integrated Pest Management)

Individuals and organizations spent considerable time and money preparing for soybean rust, a threat that did not materialize in Illinois. Was it all for nothing, or will this preparedness pay off in 2006 and beyond? What can we learn from the southern states, and what defines a credible threat for Illinois? What have we learned about the various fungicides that can be used to manage soybean rust? This symposium features four speakers who will tackle these and other important questions.

| | |
|---|---|
| 8:00 AM | Have We Wasted Time and Money on Preparedness? • *Gary Schnitkey* |
| 8:25 AM | Illinois Summary: Dust off Your Rust Plan • *Suzanne Bissonnette* |
| 8:50 AM | Perspectives from Alabama: What Did We Learn? • *Edward Sikora* |
| 9:15 am | Fungicides: What They Do and How They Work • *Martin Draper* |
| 9:40 AM | Questions and Answers |

**Symposium E—Soybean Pest Management: Then, Now, and Tomorrow** • Ballroom • *Ken Dalenberg and Rick Reed, Moderators*

(1.5 CCA credits in Integrated Pest Management)

Pest management for soybeans in the Corn Belt has changed dramatically over the past two decades. Changes in soybean production, the advent of new pest management technologies and techniques, and an influx of new pests have resulted in soybean management systems that are much different now than they were then. Soybean management systems will continue to evolve into tomorrow, with novel challenges and associated solutions developing over time. This symposium will focus on changes in soybean production and protection that affected some of the major pests in 2005, with research-based information that will provide the foundation for development of management strategies for the future.

| | |
|---|---|
| 8:00 AM | Optimizing Soybean Yields for Tomorrow with Today's Technologies • *Jeff Bunting* |
| 8:15 AM | Twospotted Spider Mites: Case Study in Soybean Pest Management • *Kevin Steffey* |

| | |
|---|---|
| 8:30 AM | Prevalent Soybean Diseases: Current Management and Future Strategies • *Jason Bond* |
| 8:50 AM | Racism (Among Nematodes) in Soybean Pest Management •*Terry Niblack* |
| 9:05 AM | Soybean Aphid and the Challenge of *Integrating* Recommendations within an IPM System • *David Ragsdale* |
| 9:30 AM | Questions and Answers |

**Symposium F—Issues in Environmental Toxicology: Science, Courtrooms, and Public Policy** • Room 314A and B • *Jerry Kirbach and Bruce Paulsrud, Moderators*

(0.5 CCA credit in Integrated Pest Management and 1.0 CCA credit in Soil and Water Management)

The debate over pesticides and their effects on the environment has been going on for decades. In this symposium, three scientists will share their unique perspectives on a range of current issues, including synergistic effects of pesticide mixtures, endocrine disrupters, endangered species and lawsuits, effects of pesticides on aquatic organisms, and ramifications of public policy. Although these issues may not seem urgent to everyone, their ultimate resolution will influence every agribusiness and field environment.

| | |
|---|---|
| 8:00 AM | Is an Airplane Really a Point Source? • *Dee Ann Staats* |
| 8:30 AM | Hazards, Hazards Everywhere; But Is There Any Risk? • *Allan Felsot* |
| 9:00 AM | Pesticides and Aquatic Communities: How Unintentional Exposures Impact Non-target Organisms • *Rick Relyea* |
| 9:30 AM | Questions and Answers |

9:45–10:15 AM Break • South Lounge

***Symposia D, E, and F are repeated concurrently from 10:15 am–12:00 NOON.***

**Symposium D (repeated)—Will That New Sprayer Get "Rusty?"** • Illini Rooms A and B

**Symposium E (repeated)—Soybean Pest Management: Then, Now, and Tomorrow** • Ballroom

**Symposium F (repeated)—Issues in Environmental Toxicology: Science, Courtrooms and Public Policy** • Rooms 314A and B

## Thursday Afternoon, January 5

A light lunch will be provided to people who attend the closing session. Lunches will be available in the South Lounge.

**Closing Session** • Illini Rooms A, B, and C • *Todd Gleason, Moderator*

(1 CCA credit in Integrated Pest Management)

New pest control technologies, bigger farms, higher production costs, global competition, and escalating emphasis to produce more and safer food are challenging us to reconsider integrated pest management (IPM) as a set of operating principles for agriculture. However, use of crop protection products as "insurance," applications of pesticide "cocktails," divergent economic thresholds from myriad sources, and peer pressure all argue for retaining IPM principles to serve both agriculture and the environment. How can these seemingly competing forces enable us to strike a balance?

This point/counterpoint discussion is intended to illuminate the issues and provide a compelling debate about IPM in the 21st Century.

| | |
|---|---|
| 12:15 PM | Introduction and Ground Rules |
| 12:20 PM | Who Needs IPM in the 21st Century? A Critical Point/Counterpoint for Agriculture |
| | *Allan Felsot, Professor and Extension Specialist, Food & Environmental Quality Lab, Washington State University, Richland* |
| | *Leon Higley, Professor of Entomology, University of Nebraska, Lincoln* |

# Program Participants

**Bissonnette, Suzanne** • Extension Educator, Integrated Pest Management, Champaign Extension Center, University of Illinois Extension, Champaign, IL

**Bellm, Robert** • Extension Educator, Crop Systems, Edwardsville Extension Center, University of Illinois Extension, Edwardsville, IL

**Black, Kevin** • Insecticide and Fungicide Manager, Growmark, Inc., Bloomington, IL

**Bond, Jason** • Assistant Professor, Department of Plant, Soil, and Agricultural Systems, Southern Illinois University, Carbondale, IL

**Bunting, Jeff** • Seed Agronomist, Growmark, Inc., Seymour, IL

**Chassy, Bruce** • Professor, Department of Food Science and Human Nutrition, University of Illinois, Urbana-Champaign, IL

**Cook, Kelly** • Extension Specialist, Integrated Pest Management, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL

**Czapar, George** • Extension Educator, Integrated Pest Management, Springfield Extension Center, University of Illinois Extension, Springfield, IL

**Dalenberg, Ken** • Treasurer, Illinois Soybean Checkoff Board, Mansfield, IL

**Draper, Martin** • Associate Professor, South Dakota State University, Brookings, SD

**Easter, Robert** • Dean, College of Agricultural, Consumer and Environmental Sciences, University of Illinois, Urbana-Champaign, IL

**Felsot, Allan** • Professor and Extension Specialist, Entomology and Environmental Toxicology, Washington State University, Richland, WA

**Gleason, Todd** • Media Communications Specialist, Information Technology and Communication Services, University of Illinois, Urbana-Champaign, IL

**Gray, Mike** • Professor, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL

**Hager, Aaron** • Assistant Professor, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL

**Heap, Ian** • Director, International Survey of Herbicide-Resistant Weeds, Corvallis, OR

**Hellmer, Mike** • Field Sales Agronomist, Pioneer Hi-Bred International, Inc., Mahomet, IL

**Hellmich, Rick** • USDA-ARS, Research Entomologist, Department of Entomology, Iowa State University, Ames, IA

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**Kirbach, Jerry** • Manager, Permits and Downstate Field Operations, Bureau of Environmental Programs, Illinois Department of Agriculture, Springfield, IL

**Loux, Mark** • Weed Science Extension Specialist, Department of Horticulture and Crop Science, Ohio State University, Columbus, OH

**Malvick, Dean** • Assistant Professor, Department of Plant Pathology, University of Minnesota, St. Paul, MN

**Nafziger, Emerson** • Professor, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL

**Niblack, Terry** • Professor, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL

**Nielsen, Bob** • Professor, Agronomy Department, Purdue University, West Lafayette, IN

**Nordwald, Mark** • Regional Manager, Mosaic Crop Nutrition, Plymouth, MN

**Paulsrud, Bruce** • Extension Specialist, Pesticide Applicator Training and Plant Pathology, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL

**Ragsdale, David** • Professor, Department of Entomology, University of Minnesota, St. Paul, MN

**Reed, Rick** • Member, Illinois Agricultural Aviation Association, Mattoon, IL

**Relyea, Rick** • Assistant Professor, Department of Biological Sciences, Unversity of Pittsburgh, Pittsburgh, PA

**Schnitkey, Gary** • Professor, Department of Agricultural and Consumer Economics, University of Illinois, Urbana-Champaign, IL

**Schwab, Greg** • Professor, Department of Agronomy, University of Kentucky, Lexington, KY

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# The First 10 Years of Transgenic Crops in North America: Facts, Figures, and Fiction

BRUCE CHASSY

Sometime during 2005, one of 8.5 million farmers located in one of about 20 to 25 countries around the world will plant, or has planted, the one billionth acre of transgenic seed. In the short space of 10 years, transgenic crops (or genetically modified organisms [GMOs], as they are called in the media) have been adopted faster than any technology in the history of agriculture. The adoption of transgenic crops has been a remarkable success story, but it has not been without controversy and failure. This report summarizes the status of transgenic crops in the United States and the world today and discusses some of the key issues in the GMO controversy.

## What Are Transgenic Crops (GMOs)?

The dictionary defines biotechnology as the use of living organisms for useful purposes and industry. In the broadest sense, products such as wine, cheese, yogurt, enzymes, and antibiotics are biotechnology products. In the early 1970s, molecular biologists developed the power to isolate genes from one organism and transfer them to another. The obvious widespread potential utility of this technology in medicine and pharmaceutical production spurred the development of an industry that called itself, with great hubris, the biotechnology industry. The industry thus preempted the word biotechnology from its traditional meaning.

The term agricultural biotechnology is commonly used in reference to genetically modified (GM) crops developed using gene splicing techniques, i.e., crops modified by genetic engineering. Modification by genetic engineering differs from more traditional genetic

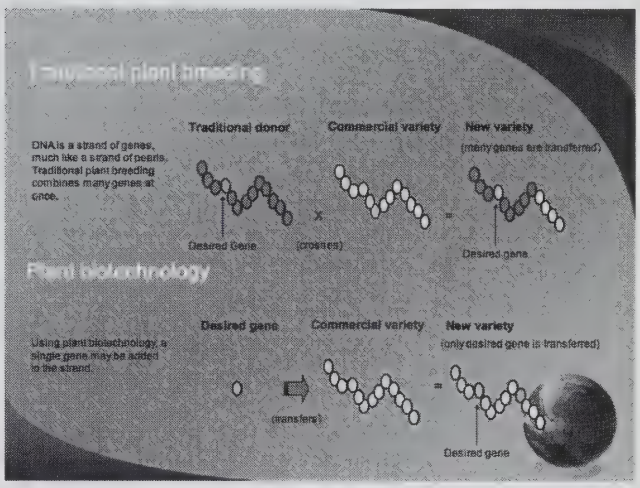



**Figure 1. Comparison of conventional breeding with gene-splicing technology used to prepare transgenic plants.**

modification in that it is done with genes that have previously been isolated and analyzed in a laboratory, which are then inserted into a crop plant (Figure 1). In reality, agricultural biotechnology is a term that can be applied to a variety of modern technologies, such as cell culture, micropropagation, molecular diagnostics, and marker-assisted breeding. Unfortunately, the terms GMO and biotechnology, which are widely and often interchangeably used in the media and in debate, do not accurately describe the construction of transgenic plants depicted in Figure 1. The term transgenics is used in this report in reference to what others call GMOs, GM plants, genetically engineered plants, or plants produced through biotechnology.

## A Brief History of Crop Breeding and the Food System

Food production and consumption are cornerstones of human existence and are major human activities. Agriculture and the food manufacturing and distribution system constitute about 20% of the gross domestic product (GDP) and work force in most developed nations and even greater numbers in the less well developed regions of the world. Food is, however, much more than simple nourishment and economic activity. Food has taken on social, cultural, artistic, and even religious significance. Most people (>98% in the United States) are dependent on others to supply their food. Consumers are, therefore, understandably intensely sensitive about the safety, quality, and wholesomeness of the food they eat. The global controversy regarding the safety of transgenic plants underscores the importance of food to society.

Agricultural settlements began to occur around 10,000 years ago. Early agriculturists domesticated plants and animals through a process of selection of genetic changes that improved crop and animal characteristics. Over a period of thousands of years, for example, Mexican farmers were able to select modern corn varieties from the wild grassy ancestor of modern corn, teosinte. A similar story can be told for most of our crops. The majority of the plants used in agriculture today bear little if any resemblance to their wild ancestors, and in some cases, do not even exist in nature (e.g., nectarines, wheat, strawberries, tangelos).

As is discussed elsewhere in this report, there is much confusion and debate about which crops are natural and which crops are not natural. Opponents of GMOs view them as decidedly unnatural. A recent review succinctly summarized the genetic nature of domesticated crops as follows (Chassy et al. 2005):

"...they [plant breeders] also directed changes in crop DNA (reviewed by Bradford et al. 2005)....In some cases, the changes have been so great that only a well-trained botanist can identify the wild ancestor of a crop. The nature of these changes has become clearer as we have been able to sequence the genetic code of domesticated plants and their wild relatives. We know now that practically all plants we eat are extensively genetically modified compared with their wild ancestors. Often these modifications have been achieved through human selection of traits introduced through interspecific hybridization or created by random mutagenesis. Many crops clearly have DNA that has come from other species. These crops are not "natural" by any definition, but have been diverted from 'natural' selection to meet human needs."

As it happens, plants produced by natural breeding are not inherently different or superior to "human-made" plants produced through biotechnology (which, to some, *artificial* implies *inferior*), nor are they benign. Nature also turns out to be a slow and inefficient engineer. Critics also claim with little scientific basis or evidence that introducing genes from organisms that would not normally cross with a crop plant is fraught with uncertainty and risk. Conversely, transgenic methods are particularly powerful and useful because they can move genes between organisms that would not normally exchange genes at an appreciable rate.

## Why Do We Need Transgenic Crops?

Other appropriate questions might be, "Why do we need to change our crops?" Or "Why do we need to change our agricultural systems?" "Why should we change our food and diets?" Although these are commonly asked questions, all seem to overlook the fact that change has occurred continuously in 1) the crop varieties we cultivate, 2) the composition of individual crop foods, and 3) the human consumption of crop foods, i.e., the human diet.

1) There are hundreds, if not thousands of varieties of most crops. They are developed to meet local growing needs, climates, and consumer preferences. The selection of varieties is continually changing as plant breeders improve growing characteristics, resistance to diseases and pests, and improve nutritional quality and appearance.

2) There is substantial evidence that different crop varieties have different compositions and nutrient values. Moreover, the same variety planted at different sites or in different years will result in wide variation in observed composition (see http://www.cropcomposition.org). It is noteworthy that all transgenic crops introduced into the market to date have compositions that fall within the normally observed ranges for varieties of that crop. Recent detailed analysis of the potato proteome (Lehesranta et al. 2005) and metabolome (Catchpole et al. 2005) demonstrate that transgenic potatoes more closely resemble the isogenic variety from which they were derived than do other potato varieties.

3) The history of the human diet is one of continual change and introduction of new and novel foods. The

relatively recent (in an evolutionary time scale) development of corn and other crops has been mentioned previously. What is often overlooked is that many of the crops we eat were only recently introduced into the local diet. Table 1 lists crops that were found in the Americas during the first hundred years of Spanish exploration (sixteenth to seventeenth centuries) that were only adopted as human food in Europe, Asia, Africa, and Australia during the past 100 to 200 years. The average Northern European eats about 300 g of potatoes a day, and potatoes are considered a traditional part of the European diet. However, potatoes became a food crop only within the past 200 years. Nothing could be more traditional and characteristic of a cuisine than tomato sauce and pasta is to Italy, yet tomatoes were introduced in Italian cuisine sometime during the past 200 years. Moreover, the traditional variety of Durum wheat from which Italian pasta is made was produced by irradiation mutagenesis in an irradiator located near Rome. Other crop plants spread around the globe from a variety of distant origins (Table 2).

**Table 1. Crops originating in the Americas**

| Crop | Origin |
|---|---|
| Avocado | Central and South America |
| Beans | Mesoamerica |
| Cacao | Aztec (xoco-latl) |
| Corn | Mesoamerican (10,000 years) |
| Cotton | South America |
| Gourds | Americas |
| Papaya | Tropical America |
| Peanuts | South America |
| Peppers | Mexico–Mesoamerica (Nightshade family) |
| Pineapples | South America |
| Potatoes | Andes mountains (Nightshade family) |
| Pumpkins | Tropical America |
| Squash | South America |
| Strawberries | Americas |
| Sunflowers | Central and North America |
| Tomatoes | Mesoamerica (Nightshade family) |

From *Guns, Germs and Steel*, Jared Diamond, and http://www.hort.purdue.edu/newcrop/history/lecture05/lec05.html.

**Table 2. Crops plants originating in Europe, Asia, and Africa**

| Crop | Origin |
|---|---|
| Barley | Fertile Cresent |
| Beets | Europe, Africa, and the Near East |
| Broccoli | Europe |
| Carrots | Central Asia and the Near East (purple) |
| Eggplant | India and China |
| Flax | Fertile Crescent |
| Hemp | China |
| Lettuce | Europe |
| Millet | China |
| Muskmelon | Fertile Crescent |
| Okra | Africa |
| Onions | Asia |
| Peas | Europe and Asia |
| Radishes | Cool regions of Asia |
| Wheat | Fertile Crescent |
| Rice | China |
| Soybean | China |
| Watermelon | West Africa |
| Sorghum | West Africa |
| Yams | Africa |

From *Guns, Germs and Steel*, Jared Diamond, and http://www.hort.purdue.edu/newcrop/history/lecture05/lec05.html.

Human dietary history has been one of continuous change. Not only are new crops and animals developed or acquired from abroad, diets vary widely by culture, age, gender, health status, socioeconomic status, and, most of all, personal preference. Not only does an individual's diet differ from those of other members of their own family, it changes with time because of changing preferences, the appearance of new products, and changing needs. The key point to remember is that an almost infinite variety of ingredients can be used to satisfy human nutritional requirements. Humans need to derive energy (from protein, carbohydrate, and lipid) and certain key essential nutrients from their diet (e.g., essential amino acids, essential fatty acids, fiber, vitamins, and minerals).

Although there clearly are healthier and less healthy diets—for example, the Mediterranean diet is healthier in the long term than a diet high in fat—humans in developed countries eat highly varied diets. The major health issue with respect to their diets is promoting wise diet choices that are known to promote better long-term health outcomes. Diets in less developed countries and among the poor frequently are less varied than those in developed countries. More than 850 million people do not have access to an adequate daily food ration and can be considered undernourished (Figure 2).

A considerable portion of the world's population suffers from malnutrition with vitamin A, folic acid, iron, and iodine deficiencies leading the list (Figure 3). Many have attributed this malnutrition to poverty, and it is true that almost 2 billion people live on less than $1 per day. This, coupled with food surpluses in developed countries, leads some to say that the reason for hunger is not a lack of food. They contend that there is no lack of food in the world and that hunger results from unequal distribution of food resources due to poverty. Sir Gordon Conway, President of the Rockefeller Foundation recently described as "naïve" those who believe there is enough food in the world and that we simply need to redistribute it. He went on to note that the situation was not that simple (see also Annan 2000, Evans 1998, Sanchez and Swaminanthan 2005).

Economists argue about whether there is enough food to feed all the world's inhabitants. Although there are differing points of view on this topic among resource economists, it seems fair to say that if all the world's

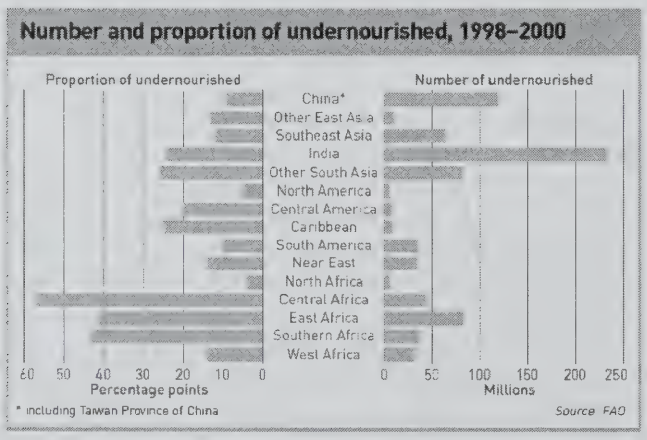



**Figure 2. Distribution of undernourishment by region.**

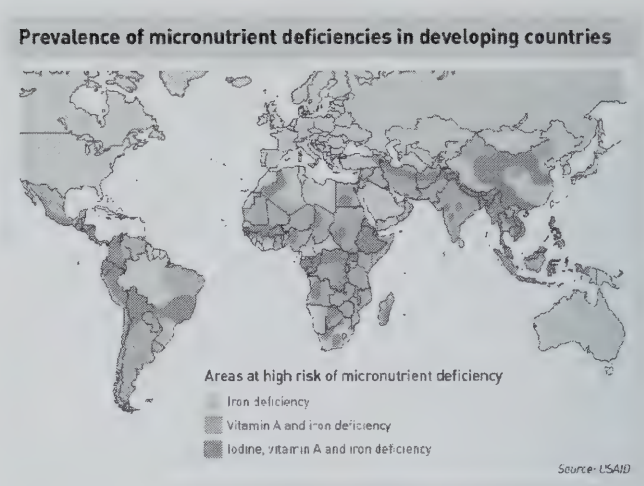

Prevalence of micronutrient deficiencies in developing countries
Areas at high risk of micronutrient deficiency
Iron deficiency
Vitamin A and iron deficiency
Iodine, vitamin A and iron deficiency
Source: USAID

**Figure 3. Map of malnutrition around the globe in 2000.**

citizens ate a plant-based diet and if food were more equitably distributed, all the world's people could be adequately nourished. Given the existing international social and political structure, it seems highly unlikely that will happen. Perhaps more important is the fact that 50% of the world's poor do not buy food. They are rural farmers who produce their own food; an additional 20% of the world's population lives in the same rural setting and depends on these same farmers for their food as well. Thus, in the absence not only of money but also of markets, warehouses, and food distribution systems, the only way to feed this growing segment of the population is to help them be able to produce enough food in a sustainable manner to be able to feed their families and have a surplus for trade or sale. It is important to note that increased agricultural productively spurred by the Green Revolution not only eliminated near-yearly famine in China and India but also that the effect of increased production on rural economic growth and development contributed to the development of the national economies.

Two additional facts support the assertion that global food production must be *doubled* in the next 25 years (http://www.fao.org/es/esd/gstudies.htm). Global population will rise 50% in the next 30 to 40 years; most of the population growth will occur in developing countries that are today least able to produce sufficient food. Agriculture accounts for 70% of the fresh water use in the world. Salt buildup in irrigated soils will cause 50% of the world's irrigated soils to become unusable in the next few decades. US$40 billion is spent on pest protection globally each year. Because of

a variety of reasons, but principally diversion of land to other uses, erosion, desertification, and growing salinity of irrigated soils, the amount of land available for farming is decreasing by about 1.5% per year. Losses of farmed lands along with increasing population mean globally that although there were 0.33 ha (~0.83 acre) per person per year on which to grow food in 1991, there will be only about 0.15 ha per person per year in 2040 (~0.36 acre). Additionally, it has been estimated that insects, weeds, and diseases decrease global crop yields by about 42% each year (Annan 2000).

To return to the question of "Why do we need GM-crops?" it should be clear that increases in agricultural productivity and sustainability are needed. The real question is what strategies and technologies will allow us to produce sufficient food in 2040 in a sustainable and environmentally acceptable manner? Can modern molecular techniques allow us to breed plants that will help meet the challenges facing agriculture? The list of needs is formidable:

1. Increased food production (more area farmed or more yield per area)
2. Protection against pests (insects, weeds)
3. Protection against diseases
4. Strategies to cope with decreased soil fertility and soil and land losses
5. Strategies to cope with decreased quality and availability of water
6. Increased tolerance to abiotic stresses
7. Environmentally friendly sustainable agriculture
8. More nutritious crops
9. Crops with greater consumer appeal

Researchers have used transgenic technology to develop plants that address many of these needs. The technology should be viewed as a tool that is used when it is appropriate. Transgenic plants are not intended to be silver bullets that cure all agricultural problems, but they should be viewed as one of several techniques that can be used to improve crops and benefit management and production systems. The question is not whether GMOs will end world hunger nor whether they will feed the world, but rather whether specific applications of the technology contribute to agricultural improvements and provide solutions to specific challenges.

## What Types of Transgenic Crops Are Being Planted, and Who is Planting Them?

Most of the transgenic crops that are being cultivated today fall into three broad categories: 1) resistant to insects by introduction of genes that encode proteins that are toxic to specific insects; 2) tolerant to specific herbicides, such as glyphosate, through the introduction of a form of an enzyme that is not inhibited by the herbicide; and 3) resistant to diseases, primarily viral diseases. These traits also have been combined in some crops, for example, herbicide-tolerant and insect-resistant corn.

In the United States in 2004, the major transgenic crops planted were soybean, canola, cotton , and corn, which were planted on 85, 77, 76, and 45% of the respective crop acres (Brookes and Barfoot 2005). Virus-resistant papaya (55%) and squash (9%) and small amounts of insect resistant sweet corn (~1%) also were grown. The global planting of the major transgenic crops is shown in Figure 4 (Brookes and Barfoot 2005).

The proportion of each major crop that is transgenic is shown in Figure 5 (Brookes and Barfoot 2005).

The yearly adoption of each of these crops is shown in Figure 6 (Brookes and Barfoot 2005).

The distribution of transgenic crop planting by trait and crop is shown in Figure 7 (Brookes and Barfoot 2005).

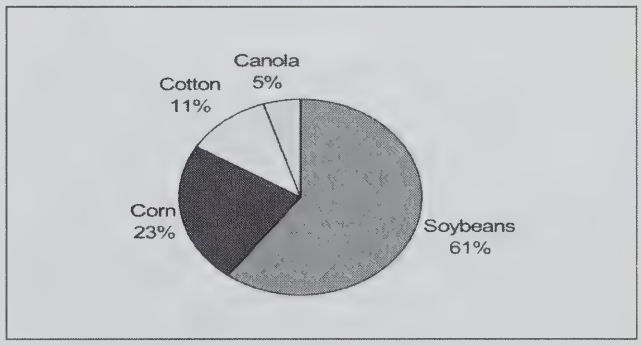



**Figure 4. GM crop plantings by crop area (base area 77.5 million hectares).**

Sources: Various including ISAAA, Canola Council of Canada, CropLife Canada, USDA, CSIRO, ArgenBio

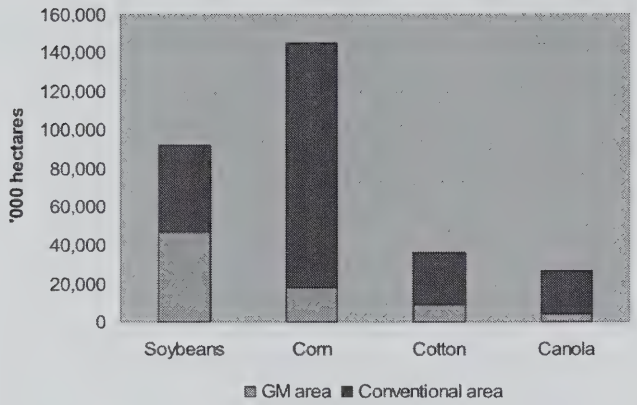



**Figure 5. 2004's share of GM crops in global plantings of key crops ('000 hectares).**

Sources: Various including ISAAA, Canola Council of Canada, CropLife Canada, USDA, CSIRO, ArgenBio

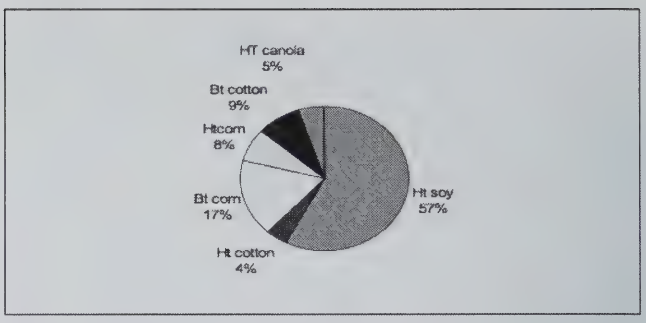



**Figure 7. Global GM crop plantings by main trait and crop: 2004.**

Sources: Various including ISAAA, Canola Council of Canada, CropLife Canada, USDA, CSIRO, ArgenBio

Adoption of transgenic crops by country is presented in Figure 8 (Brookes and Barfoot 2005).

These data demonstrate that two traits (insect resistance and herbicide tolerance) in four major crops (soybeans, corn, cotton, and canola) are the major transgenic crops planted today. They also demonstrate that the United States and Argentina are the primary users of transgenic crops, with Canada, Brazil, and China planting a few percent each. Transgenic crops are planted in at least 17 countries (James 2004). Although it is a commonly held belief that transgenic crops are not grown in the European Union, Spain, Germany, and Romania have planted transgenic crops. In 2005, a large number of French farmers planted small test plots of insect-protected corn. Based on satisfactory results in 2005, much greater acreage of transgenic crops will be planted next year in France. This increase is possible because several European Union countries have approved transgenic crops but do not grow them.

It is often claimed that GM technology is designed to benefit the large agricultural biotechnology companies that market transgenic seeds. The argument also is made that transgenic seeds are suitable only for large-scale farming in developed countries and would further disadvantage poor farmers in developing countries. The facts do not seem to support this view. In fact, 7.5 million out of the 8.5 million farmers that planted transgenic crops in 2004 were small holders who live in

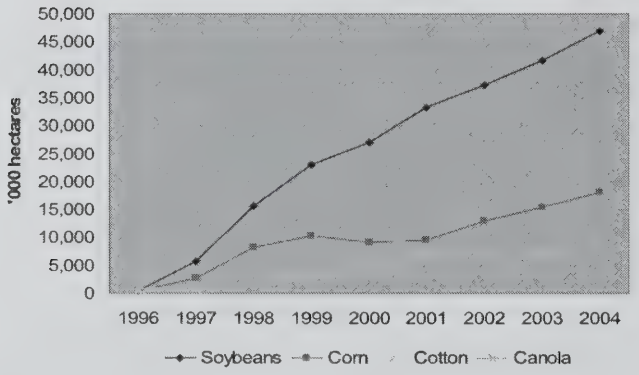



**Figure 6. Global GM crop plantings by crop 1996–2004.**

Sources: Various including ISAAA, Canola Council of Canada, CropLife Canada, USDA, CSIRO, ArgenBio

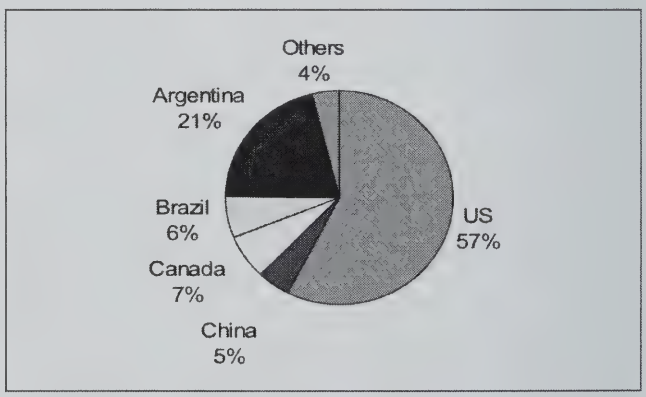



**Figure 8. Global GM crop plantings in 2004 by country.**

Sources: Various including ISAAA, Canola Council of Canada, CropLife Canada, USDA, CSIRO, ArgenBio

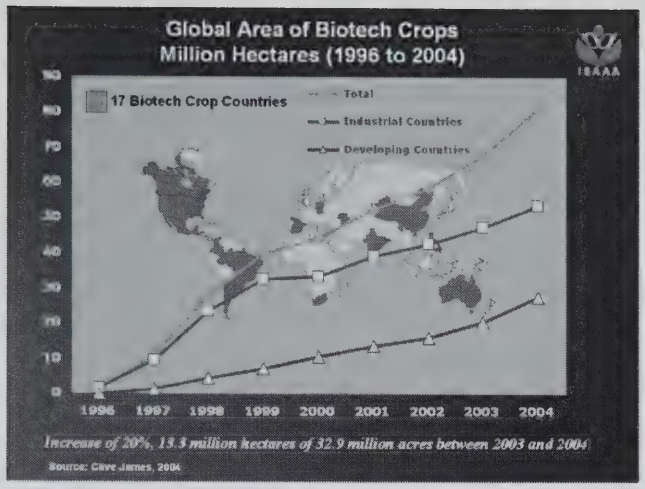

Global Area of Biotech Crops
Million Hectares (1996 to 2004)
17 Biotech Crop Countries
Total
Industrial Countries
Developing Countries
1996 1997 1998 1999 2000 2001 2002 2003 2004
Increase of 20%, 13.3 million hectares of 32.9 million acres between 2003 and 2004
Source: Clive James, 2004

**Figure 9. Acres of biotech crops planted in industrialized and developing countries.**

developing countries (James 2004). Moreover, planting transgenic crops in developing countries is increasing rapidly (Figure 9, James 2004). Biotechnology is not the sole-property of industrialized countries or large corporations. China, India, Vietnam, and Cuba are countries that are making a large public sector investment in biotechnology. Although some new developments are discussed in a forthcoming section; it is important to point out here that researchers in universities, research institutes, government laboratories, and foundations around the global are engaged in thousands of research and development (R&D) projects that use transgenic strategies in their crop development. The direct use of this technology to address regional problems in developing countries has been evaluated (Cohen 2005). More than 200 public-sector projects have been identified in some 37 developing countries. Large multinational corporations may seem to be villains to some, but to many poor farmers around the world, large corporations have provided seeds that have increased productivity and profitability, as is documented elsewhere in this report. Farmers have voluntarily paid higher prices for seeds that they believe offer them an improved bottom line. Several multinational biotechnology companies compete with domestic biotechnology seed companies for market share in some countries, whereas in other countries, poor farmers plant seeds developed by their own governments. Is this a situation that can be described as enslavement of farmers by multinational corporations?

## Benefits and Costs of Transgenic Crops

***Economic, Environmental, and Health Benefits.*** Does the technology work? It is difficult to dissociate economic impact from environmental benefits of transgenic crops because some of the benefits are because of reduction in cost of inputs that also have negative impacts on the environment and farm worker health. Based on 10 years of cropping data, any real safety and productivity gains should be well documented. In general, the experience with transgenic crops has been one of improved yields and profitability that lead to decreased costs for consumers; decreased pesticide, energy, and labor inputs; improvements in biodiversity, and in water and soil quality; and improvements in food safety and farm worker health. The value of agricultural biotechnology to farmers, consumers, and the environment in the United States has been analyzed, and the summary data are shown in Table 3. (For a discussion of effects of transgenic crops on the environment and biodiversity, refer to Heimlich et al. 2000, Pimentel and Raven 2000, Trewavas 2001, Fawcett and Towery 2002, Sneller 2003, Tabashnik et al. 2003, Amman 2005, Carrière et al. 2005, and Naranjo et al. 2005).

A similar picture is seen globally where it is estimated that that there have been substantial net economic benefits at the farm level amounting to a cumulative total of $27 billion. The technology has decreased pesticide spraying by 378 million pounds and has decreased the environmental "footprint" associated with pesticide use by 14%. The technology also has significantly reduced the release of greenhouse gas emissions from agriculture, which is equivalent to removing nearly five million cars from the roads (Brooke and Barfoot 2005).

**Table 3. Net benefits of transgenic crops in the United States**

| Year | Planted acres (million acres) | Yield increase (billion kg) | Net economic impact (billion dollars) | Pesticide use reduction (million kg) |
|---|---|---|---|---|
| **2003** | 106 | 2.4 | 1.9 | 21.0 |
| **2001** | 80 | 1.7 | 1.5 | 20.7 |

Source: NCFAP, Washington, DC. 2005. http://www.ncfap.org.

Evidence that transgenic technology can be helpful in developing countries also is accumulating. A recent report (Chassy et al. 2005) pointed out the following:

"At an estimated $US 5 billion per year, China is the world's largest user of chemical pesticides. Cotton is the most pesticide-intensive major crop plant. Transgenic cotton initially was planted in China in 1998 and now represents 50% of the cotton acreage. Yields have improved 10–30%, pesticide usage has fallen 50–80%, and profitability for small farmers has been improved significantly—in fact, those farmers who planted biotech cotton in 2001 and 2002 were more likely to make a profit, whereas those who did not plant biotech varieties lost money. Equally important, pesticide poisonings from insecticides used on cotton have been decreased by approximately 75% among farmers using biotech cotton (Pray et al. 2002). Before 1996, an estimated 10,000 insecticide poisonings and approximately 400 deaths occurred annually in Chinese cotton growing regions (from sources in Huang et al. 2003)."

Mycotoxins have long been associated with liver, kidney, and esophageal cancer (Wu et al. 2004). The mycotoxin fumonisin can be fatal to horses and pigs. It has been estimated that mycotoxins cost U.S. agriculture approximately $1 billion per year. It has recently been shown that mycotoxin consumption leads to a high incidence of birth defects (neural tube defects, NTDs) in populations that consume a diet rich in whole maize products. Maize protected against boring insects through biotechnology is found to have strikingly lower levels of the causative mycotoxin fumonisin (Shelton et al. 2002). This effect can be readily understood from Figure 10.

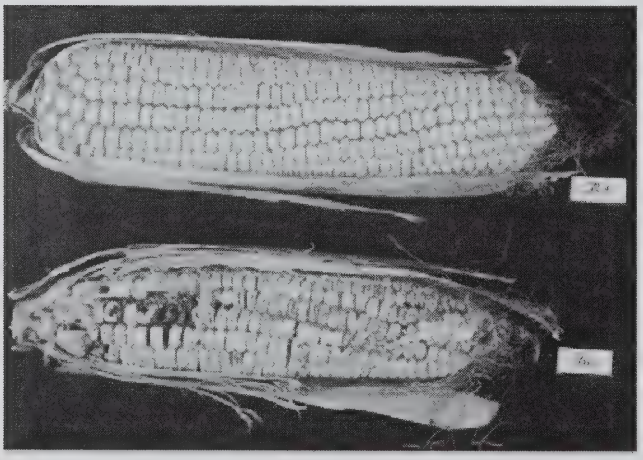


**Figure 10. Conventional and transgenic corn (Bt corn protected against boring insects).**

***Is Biotechnology a Magic Bullet for Agriculture?*** The answer would have to be no. Transgenic crops are designed for specific applications and must be used appropriately; they are not a panacea. Although a number of economic and environmental benefits attributed to transgenic crops have been documented, these benefits are averages. In specific instances, transgenic technology may not be necessary or may be more costly than alternative management strategies. It is noteworthy that the price of competitive agrochemicals has been reduced in recent years, making them cost-competitive with biotechnology solutions. This, of course, does not take into account differences in environmental costs and impacts.

Although insect resistance to transgenic crops seems to have been kept under control during the first 10 years of planting insect-protected crops, weed management remains a major challenge in the management of transgenic crops. Continued monitoring and good stewardship are necessary to maintain the effectiveness of transgenic crops.

As is discussed in following sections, the major issues associated with biotechnology crops are related to effects on trade, regulatory restrictions, negative consumer attitudes, and continued nearly global active opposition against the deployment of transgenic crops.

***Benefits to Food Security and Food Safety.*** There is no compelling evidence that transgenic crops have contributed greatly to food security. There are several reasons for this lack of evidence. The first and most obvious reason is that transgenic crops have not been widely planted in developing countries. Less R&D has been done on the development of varieties of commonly grown crops in developing countries or for versions of currently available commercial transgenic crops that are suitable for specific locales. Moreover, lack of biosafety regulations and/or a regulatory infrastructure has impeded the testing and deployment of transgenic crops in the countries where they are most needed. Concerns about access to intellectual property rights also have hindered progress. All of these barriers have been recognized and positive steps have been taken to remove or reduce their impact. Development is, at this point, largely restricted by resource availability (Cohen 2005).

Benefits of transgenic crops to food safety are equally obscure. It can be argued that Bt corn has lower concentrations of fumonisins. It is also the case that herbicide-tolerant crop products are contaminated with fewer weed seeds. The transgenic crops that are cultivated today were designed to be as safe as their conventional counterparts. They were not developed with the intent of improving food safety. Over the course of the first 10 years of their use, there has not been a single scientifically documented incident of harm to humans from the consumption of GM foods. It is unfortunate that a number of Internet sites erroneously make contrary claims that are more fantasy than fact. The record of comparative safety can be attributed to the inherent safety of plant breeding and the close regulatory scrutiny required for approval of transgenic crops.

The crux of the anti-GMO argument about food safety is that our knowledge of genes and genomes is limited and not perfect. They contend that insertion of genes from unrelated species is unnatural, and, as a consequence, may produce unknown unintended effects. This issue has been carefully studied on several occasions by the U.S. National Academy of Sciences (NAS 2004), which has repeatedly concluded that biotechnology is no more likely to produce unintended effects than conventional technology. The greater precision and more defined nature of the changes introduced through biotechnology may actually be safer. Recently, a group of scientists from the European Union (Cellini et al. 2004) addressed this same issue and concluded the following:

- All breeding has unintended effects.
- There is no reason to believe that unintended effects will be greater from modern biotechnology than from conventional breeding.
- There are many reasons why there may be fewer unintended effects from biotechnology than from conventional breeding.
- Most of the unintended effects in biotech plants arise from the conventional breeding portion of their development.

## The Downside of Transgenic Crops—Myths and Realities

***Science Meets the Media and The Activists.*** Surveys over the past few years of attitudes of consumers around the world show nearly global concern among consumers about the safety of foods produced through biotechnology. Studies also show that consumers cannot define genes, DNA, or transgenic plants, nor explain what is a GMO and what is not a GMO. GMO safety does not seem to be a major food safety concern in open-ended, unprompted surveys. The best that can be said is that many consumers have lingering concerns and do not think that they are well informed about biotechnology, but biotechnology is not a top-of-mind issue for most of them.

It is worth asking where negative perceptions of transgenic crops originate. Most consumers name television as their major source of information, followed by print media and radio. Concerns about GMOs can be traced directly to virtually 100% negative media coverage that warned of the risks of a new technology about which consumers knew very little (Abbott et al. 2001a, b). The media has failed to highlight the successes and safety of biotechnology. Journalists would counter that it is their job to present balanced coverage in a nonjudgmental manner. From the media point of view, there is a controversy about GM safety and it is their job to report on it.

For a variety of reasons, various groups have openly opposed transgenic crops. There are Web sites, books, and even movies that vividly describe the safety hazards the authors claim are associated with GM technology. Antibiotechnology groups paint transgenic plants as simply another step in the industrialization of agriculture, and they have named GMO foods "Frankenfoods." Anti-GMO activists have a long list of claims about the dangers of biotechnology that are repeated so often that they have become widely accepted as true—some would say myths or urban legends. They protest at biotechnology meetings, G8 meetings, and World Trade Organization meetings. Activists organize anti-GMO campaigns at the grass roots level in communities. For example, it is illegal to grow GM crops in Vermont or Mendocino County, CA. (Never mind that there are no GM crops that are appropriate to their local agriculture.) Anti-GMO campaigns have been well funded, well organized, and well executed campaigns that have used the tools of the information age to maximum effect. In all fairness, one would have to say that the anti-GMO campaign has understood how free societies form opinions and make policies and has exercised their political right to be heard.

Opposition to GMOs has resulted in outright bans of transgenic crops, requirements for products containing transgenic ingredients to be stigmatized by mandatory labels that consumers read as safety warnings, and

scrutiny by governments around he world to subject transgenic crops to stringent regulatory controls that are not commensurate with real risk. The anit-GMO groups also have succeeded in keeping some developed products such as GMO wheat, GMO potatoes, and GMO rice off the grocery shelves. They have created barriers to trade and enforced expensive crop segregation and mandatory testing on the food distribution system. As a consequence, farmers all over the world must think twice about whether they want to plant a GM crop. First, farmers must ask themselves if the choice would be profitable and appropriate for their needs, and then they must ask themselves if someone will buy their harvest at a reasonable price. By any measure, the anti-GMO campaign has been a successful effort.

Most industries today describe themselves as consumer-driven, and would add that the consumer is always right and that the industry's job is to give the consumers what they want. Politicians and policy-makers don't like to lose votes through unpopular positions, and they tend to be consumer-driven, as well. Politicians would describe this as responding to the will of the people. This leads to a "perception is reality" control of what is marketed to consumers. The market does not ask if the science is right or wrong; it responds to what the customer wants.

Most of the scientific community does not take a position on the question "Are GMOs safe or dangerous?" because it is not an appropriate scientific question. Each transgenic plant presents different potential benefits and may pose different risks. The scientific community focuses on specific issues associated with these individual cases. Scientists may disagree with one another and engage in heated debate on the methodology or interpretation of specific data sets. Although such debate and criticism are important components of the scientific method, dissenting scientific views about GMOs often have been taken out of context and presented to support the conclusion that GMOs are unsafe. Scientists also tend to avoid interacting with the media and, for the most part, do not engage in the public debate about GMOs.

***The Blame Game.*** If one assumes that transgenic crops are as safe as any other crop and accepts that there are 10 years of practical evidence and a substantial amount of published research to support the claim that GMOs should be treated like any other crop, we could ask how we ended up where we are today with GM crops. It is human nature to analyze a situation gone wrong and find fault with someone. In the case of agricultural biotechnology, there is plenty of blame to go around.

It would be easy enough to claim that the anti-GMO activists are ideologically driven and are not scientifically accurate and to blame them. One could also blame industries and governments that profit from nontariff trade barriers and higher prices for GMO crops (Graff and Zilberman 2004). One could blame organic crop producers and agrochemical companies who support anti-GMO opposition. But all of this blaming would miss the point. All of these interests have a right to represent their interests in the best way that they can.

If the public has not heard the whole story about GMOs, it is because a number of key participants haven't contributed to the public dialog. One can single out the biotechnology industry itself for doing a poor-to-awful job of public relations and public education for most of the first 10 years, although some recent evidence suggests that the industry may be coming to grips with the challenges they face. Government regulators and scientists are not paid to educate the public or take positions on controversial issues. In fact, democratic societies usually discourage the government from attempting to shape opinion on issues. What we expect of government is full disclosure and transparency. Regulatory agencies do not earn good marks in this regard either. As noted previously, the scientific community has not been deeply engaged in public discourse about GMOs. And finally, the food industry has assiduously avoided talking to their customers about the issue unless it is to say "We do not use GM ingredients in our foods." Transgenic plants have almost become orphans without advocates.

***What Does the Future Hold?*** There is no reason to believe that the farmed area of transgenic crops won't continue to expand around the world. China, Vietnam, and Iran are poised to approve and grow transgenic rice varieties. India has committed itself to the deployment of a new generation of insect-protected vegetables. R&D projects in several important crops in developing countries are just now reaching the stage of field testing. Each year new crops and additional countries are added to the list of nations planting GM seeds. The expansion of the technology continues. It is hard to discern how the continuing anti-GMO campaign will affect the spread of transgenic technology.

There are at least five issues that may be key in determining the future of transgenic plants in agriculture:

1) New and improved varieties that will be very attractive for farmers are now available, and others will soon be commercialized. Notable are plants with stacked traits, such as corn borer- and corn rootworm-resistant and herbicide-tolerant corn and multiple insect-resistant and herbicide-tolerant cotton. These varieties offer the possibility for a farmer to use no chemical insecticides and to make only one trip into the field to plant, one trip to spray season-long herbicide protection, and one trip to harvest. These next generation seeds will improve yields and lower costs, thus making the economic and environmental arguments in their favor more compelling.

2) New kinds of traits are being developed that will improve agriculture in now marginal lands. Plants with salt tolerance, drought tolerance, and resistance to other abiotic stresses are being tested in greenhouses and fields around the world. Transgenic technology has been applied to vegetable crops, fruit trees, grasses, and ornamental and forest tress. Many of these applications will offer compelling economic and environmental benefits.

3) It is often said that consumers would be interested in this technology if it offered them more obvious and compelling benefits. Although it can be argued that higher yields and lower costs of production, along with reduced worker injury and reduced impact of agriculture on the environment, are benefits shared by all, and some have even argued that commodity prices are a few percent lower because of biotechnology, these are not tangible benefits to consumers. A number of nutritionally enhanced or otherwise healthier-to-eat crops have already been approved or are in the future commercialization pipeline. Heart healthy oils, higher fiber plants, plants offering better mineral absorption, and plants with higher vitamin content are but a few examples. It will be interesting to see if and how food retailers offer these new products to the public. If they do, and if they are widely accepted, much of the angst over biotechnology likely will dissipate.

4) Some economists argue that markets ultimately are driven by objective economic realities. However arguable that may be, it seems reasonable to conclude that if the economics and associated benefits of transgenic crops are sufficiently compelling, transgenic crops will eventually be even more widely adopted. The high rate of repeat plantings seems to indicate that the crops perform well enough. Continuing safe experience and open markets will support further adoption.

5) Risk researchers tell us that as we become more familiar with a novel technology, our perception of risk diminishes. Good access to information from trusted authorities quickly diminishes risk concerns as well. The public discussion of GMOs has not benefited from balanced information flow. As noted perviously, the scientific community has not been deeply engaged in public discourse about GMOs. Enhanced outreach and education efforts would put the debate on a more solid scientific footing. This effort would likely help drive the acceptance of biotechnology, but even if it does not, at least society will have acted on good information. In this regard, it is noteworthy that anti-GMO activists often complain bitterly when academics make what they perceive to be probiotechnology comments. What could it be that they fear?

## Final Thoughts

On the whole, transgenic plants have been widely adopted and seem to have performed as intended or better than expected. The adverse environmental and health effects forecast by critics have not occurred to date and seem unlikely to occur. Opposition to agricultural biotechnology has had its effect as well. Doubt about transgenic crops remains with many consumers.

In many ways, transgenic crops are not what their opponents or their advocates have claimed. They have proven neither disastrous nor magical. They are everything we've heard they are, and less. We may eventually realize that too much time has been spent debating this issue and too many resources have been misdirected to ensure GMO safety, test for GMO content, and produce GMO-free products. The debate over GMOs could prove to be the wrong issue at the wrong time, because other food safety and nutrition issues loom much larger for society: food security, healthy diet choices, food borne illness, and mycotoxins, to name a few. The need for sustainable increases in agricultural productivity with concurrent reduction in the environmental footprint of agriculture should not be overlooked. Suitable alternative solutions have yet to be advanced. The whole debate may, thus, be an example of what has been called "damage by distraction" (Ames and Gold 2000)

## References


Abbott, E. A.; T. Lucht, J. P. Jensen, and Z. Jordan-Conde. 2001. Riding the hoopla: an analysis of mass media coverage of GMOs in Britain and the United States. Science Communication Interest Group, Association for Education in Journalism and Mass Communication, Washington DC.

Abbott, E. A; T. Lucht, J. P. Jensen, and Z. Jordan-Conde. 2001. Handling of GM crop issues by the mass media, pp. 23–27. *In* Proceedings of the 2001 Illinois Crop Protection Technology Conference, University of Illinois Extension, Urbana-Champaign.

Ammann, K. 2005. Effects of biotechnology on biodiversity: herbicide-tolerant and insect-resistant GM crops. Trends in Biotechnology 23: 388–394. http://www.botanischergarten.ch/TIBTECH/Ammann-TIBTECH-Biodiversity-2005.pdf.

Ames, B. N., and L. S. Gold. 2000. Paracelsus to parascience: the environmental cancer distraction. Mutation Research 447: 3–13.

Annan, K. A. 2000. Millennium Report of the Secretary-General of the United Nations. http://www.un.org/millennium/sg/report/index.html (18 October 2005).

Bradford, K. J., A. Van Deynze, N. Gutterson, W. Parrott, and S. H. Strauss. 2005. Regulating transgenic crops sensibly: Lessons from plant breeding, biotechnology and genomics. Nature Biotechnology 23: 439–444.

Brookes, G., and P. Barfoot. 2005. GM crops: the global economic and environmental impact—The first nine years 1996–2004. AgBioForum 8:187–196.

Carrière, Y., C. Ellers-Kirk, M. Sisterson, L. Antilla, M. Whitlow, T. J. Dennehy, and B. E. Tabashnik. 2003. Long-term regional suppression of pink bollworm by *Bacillus thuringiensis* cotton. Proceedings of the National Academy of Sciences (USA) 100: 1519–1523.

Catchpole, G. S., M. Beckmann, D. Enot, M. Mondhe, B. Zywicki, J. Taylor, N. Hardy, A. Smith, R. King, D. Kell, et al. 2005. Hierarchical metabolomics demonstrates substantial compositional similarity between genetically modified and conventional potato crops. Proceedings of the National Academy of Sciences (USA) 102: 14458–14462.

Cellini, F. A., A. Cheson, I. Colquhoun, A. Constable, H. V. Davies, K. H. Engel, A.M.R. Gatehouse, S. Kärenlampi, E. J. Kok, J. J-Leguay, et al. 2004. Unintended effects and their detection in genetically modified crops. Food and Chemical Toxicology 42: 1089–1125.

Chassy, B., W. Parrott, and R. Roush. 2005. Crop biotechnology and the future of food: a scientific assessment. Council for Agricultural Science and Technology. Washington, DC.

Cohen, J. I. 2005. Poorer nations turn to publicly developed GM crops. Nature Biotechnology 23: 27–33. http://www.ifpri.org/pubs/articles/2005/naturebiotech.pdf (18 October 2005).

Evans, L. T. 1998. Feeding the ten billion: plants and population growth. Cambridge University Press, Cambridge.

[FAO] Food and Agriculture Organization of the United Nations. 2000. World Agriculture Towards 2015/2030, Summary Report. http://www.fao.org/documents/show_cdr.asp?url_file=/DOCREP/004/Y3557E/Y3557E00.HTM (18 October 2005)

Fawcett, R., and D. Towery. 2002. Conservation tillage and plant biotechnology: how new technologies can improve the environment by reducing the need to plow. Conservation Technology Information Center, Purdue University. http://www.ctic.purdue.edu/CTIC/Biotech.html (18 October 2005).

Graff, G. D., and D. Zilberman. 2004. Explaining Europe's resistance to agricultural biotechnology. Update Agricultural and Resource Economics, University of. California-Berkeley 7: 1-4.

Heimlich, R. E., J. Fernandez-Cornejo, W. McBride, C. Klotz-Ingram, S. Jans, and N. Brooks. 2000. Genetically engineered crops: Has adoption reduced pesticide use? Agricultural Outlook. USDA-ERS, August. Washington, DC.

Huang, J., R. Hu, C. Pray, F. Qiao, and S. Rozelle. 2003. Biotechnology as an alternative to chemical pesticides: a case study of Bt cotton in China. Agricultural Economics 29: 55–67.

James, C. 2004. ISAAA (International Service for the Acquisition of Agri-Biotech Applications) Briefs No. 32-2004, Preview: Global Status of Commercialized Biotech/GM Crops: 2004. Manila, Philippines.

Lehesranta, S., H. Davies, L. Shepherd, N. Nunan, J. McNicol, S. Auriola, K. Koistinen, S. Suomalainen, H. I. Kokko, and S. Kärenlampi. 2005. Comparison of tuber proteomes of potato varieties, landraces, and genetically modified lines. Plant Physiology 138: 1690–1699.

Naranjo, S. E., G. Head, and G. P. Dively. 2005. Field studies assessing arthropod non-target effects in Bt transgenic crops. Environmental Entomology 34: 1178–1376.

[NAS] National Academy of Sciences. 2004. Safety of genetically engineered foods: approaches to assessing unintended health effects. National Academy of Sciences, Washington, DC. http://books.nap.edu/catalog/10977.html?onpi_newsdoc07272004 (18 October 2005).

Pimentel, D., and P. H. Raven. 2000. Bt corn pollen impacts on nontarget Lepidoptera: assessment of effects in nature.

Proceedings of the National Academy of Sciences (USA) 97: 8198–8199.

Pray, C. E., J. K. Huang, R. F. Hu, and S. Rozelle. 2002. Five years of Bt cotton in China—the benefits continue. The Plant Journal 31: 423–430.

Sanchez, P. A., and M. S. Swaminanthan. 2005. Cutting world hunger in half. Science 307: 357–359.

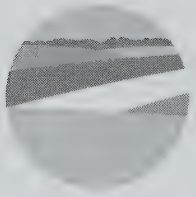
Shelton, A., J. Zhao, and R. Roush. 2002. Economic, ecological, food safety, and social consequences of the deployment of Bt transgenic plants. Annual Review of Entomology 47: 845–881.

Sneller, C. H. 2003. Impact of transgenic genotypes and subdivision on diversity within elite North American soybean germplasm. Crop Science 43: 409–414.

Tabashnik, B. E., Y. Carrière, T. J. Dennehy, S. Morin, M. S. Sisterson, R. T. Roush, A. M. Shelton, and J. Z. Zhao. 2003. Insect resistance to transgenic Bt crops: Lessons from the laboratory and field. Journal of Economic Entomology 96: 1031–1038.

Trewavas, A. J. 2001. The population/biodiversity paradox. Agricultural efficiency to save wilderness. Plant Physiology 125: 174–179.

Wu, F. A., J. D. Miller, and E. A. Cassman. 2004. The economic impact of Bt corn resulting from mycotoxin reduction. Journal of Toxicology—Toxin Reviews 23: 397–424.



# The Day after Yesterday

## Weed Management Issues in 2005, with Expectations for 2006

Aaron Hager

The 2005 growing season probably will be remembered several different ways. Some undoubtedly will recall the season as one of the driest in recent memory, with many challenges resulting from the lack of appreciable soil moisture. For others, albeit many fewer, soil moisture was reasonably good for much of the season, and they experienced fewer challenges resulting from dry soil conditions. Although we acknowledge weed management questions emanated from those who were fortunate enough to experience good soil moisture levels, the majority of the following text focuses on weed management challenges that were, for the most part, directly related to dry soil conditions. For many affected by dry soils in 2005, to describe weed management merely as "challenging" would be comparable with describing the parting of the Red Sea as "interesting." Across much of Illinois, the 2005 season was marked by cold, dry periods that were followed by hot, dry periods. Weed control in 2005 was, in very general terms, poor relative to that in 2004.

Soil-applied herbicides continue to be widely used for weed management in corn. Older "standards" and newer premix products offer many advantages to the corn farmer, but soil-applied herbicides all have the same Achilles heel: when applied to the soil surface, these products require either mechanical incorporation or precipitation to move them into the soil solution. For a soil-applied herbicide to be effective, the herbicide needs to be available for uptake by the weed seedling. For a herbicide to be absorbed by weed seedlings, the herbicide must be in the soil solution or vapor phase (i.e., an available form). Without mechanical incorporation, precipitation becomes essential to move the herbicide into the soil. Soil-residual herbicides applied to a dry soil surface often did not receive an "activating" rainfall for several days or weeks after application, which contributed to generally poor performance of many products. Overall (but with exceptions), we observed perhaps the poorest weed control from soil-applied treatments in the herbicide evaluation trials at Urbana in 2005 as has occurred in many years. This observation held for both corn and soybean soil-applied herbicide treatments.

During early May, much of Illinois experienced air temperatures low enough to damage emerged corn. In situations where corn replanting was justified, controlling the remaining corn plants before replanting was often accomplished with tillage or glyphosate. However, in instances where tillage was not an option **and** the existing corn was a glyphosate-resistant hybrid, farmers faced a situation few previously had considered. How does one control glyphosate-resistant corn before replanting without the option for tillage? Several asked about the possibility of applying ACCase-inhibiting herbicides (such as clethodim, sethoxydim, and fluazifop), which can effectively control emerged corn, but each of these product labels carry rotational intervals between application and planting corn. Poast Plus is labeled for preplant applications, but applications must be made at least 30 d before corn planting. The labels of Select, Fusion, Fusilade DX, and Assure II indicate rotational intervals of 30, 60, 60, and 120 d, respectively, between application and corn planting. Thus, other control options were sought.

We moved into the postemergence herbicide application window with corn across the state ranging from frost-damaged to actively growing. Enhanced potential for crop injury and poor weed control from many

postemergence herbicides were topics that dominated numerous conversations. Crop injury concerns were elevated because of the adverse growing conditions the corn plants had endured. We encouraged the use of leaf collars over corn height when determining the stage of corn development, especially if corn plants had experienced significant damage from frost. We even suggested an additional "safety factor" would be to count the existing leaf collars and add one. When air temperatures once again returned to more normal levels, crop injury concerns also returned to more "normal levels."

The poor performance of many soil-applied herbicides led to subsequent (and sometimes very robust) populations of grass and broadleaf weed species in many cornfields. Postemergence applications were made to fields where the application was part of a planned program, and to fields where farmers had not planned to treat weeds after corn emergence. Regardless of whether planned or "spontaneous," many postemergence products were applied to weeds that were "hardened off' and difficult to control because of the persistently dry soils. Resprays were frequent and often occurred to control weeds missed during the initial postemergence application. The lack of activity from soil-applied herbicides coupled with the often reduced activity of postemergence herbicides combined to result in a potpourri of weed species poking above the crop canopy during late summer. Across much of central Illinois, velvetleaf and giant ragweed were common species overtopping corn, whereas waterhemp was very common in many fields in central and southern Illinois.

As crop harvest progressed and farmers began preparations for fall seeding of wheat, concerns were expressed about the potential for crop injury caused by herbicide carryover. Poor weed control was one of the obvious outcomes of the dry growing season, but herbicide degradation and dissipation also can be reduced when soil moisture is limited. Reduced herbicide dissipation in soils can result in herbicide residues high enough to cause injury to susceptible rotational crops. Although concerns about herbicide carryover injury to wheat were foremost in the minds of many farmers during harvest, carryover concerns for the 2006 corn and soybean crops remain on the minds of many.

## Other Items of Interest from 2005

In April 2005, we reported on horseweed (*Conyza canadensis*) populations from three Illinois counties that were not controlled with glyphosate in greenhouse experiments. We speculate additional horseweed populations exist in Illinois that are not controlled with glyphosate, and we urge farmers to consider using additional or alternative herbicides for horseweed control when possible.

Common lambsquarters (*Chenopodium album*) control with glyphosate was inconsistent across several areas of Illinois in 2005. Poor control was reported after either burndown applications or in-crop applications. Factors such as poor spray coverage and plant size did not always explain why some plants survived while others were effectively controlled. Most reports from the field indicated that common lambsquarters plants missed by a first application of glyphosate were controlled by glyphosate after a subsequent application.

Two species of *Amaranthus* not controlled with glyphosate were identified in four states during 2005. Palmer amaranth (*Amaranthus palmeri*) populations in Georgia, North Carolina, and Tennessee and two populations of waterhemp in Missouri were reported to have various levels of tolerance or resistance to glyphosate in field and greenhouse trials. Both of these species are dioecious (i.e., open pollinated), can exist at very dense populations in agronomic crops, and are indigenous to Illinois. Palmer amaranth is predominately found in the southern one-third of Illinois (approximately from Mt. Vernon south), whereas waterhemp can be found across most of Illinois. These examples from other states should serve as additional evidence that resistance to glyphosate can occur and that resistance is possible in agronomically important weed species that are problem species for Illinois farmers.

The number of acres planted with glyphosate-resistant corn hybrids in Illinois during the 2005 growing season increased over previous years. Farmers growing glyphosate-resistant corn used a broad range of weed management techniques, ranging from applying a full or reduced rate of a soil-residual herbicide close to planting to relying exclusively on a postemergence application of glyphosate. It is likely that the dry soil conditions of 2005 reduced the amount of time the corn crop could compete with weeds before crop yield was significantly reduced, especially in fields were no soil-residual herbicide had been applied.

Poor crop canopy development coupled with precipitation in August resulted in hearty populations of hophornbeam copperleaf (*Acalypha ostryifolia*) present in many fields across central Illinois at crop harvest. These plants usually are small in stature (less than 18

in. in height), but dense populations between the rows of mature corn or soybean often cause a fair amount of concern from farmers. These "late-season" populations are not very competitive with the crop, but they may cause a slow down of the harvesting operations because of the green plant material going through the combine.

In summary, there may not be clearly defined differences between what we learned and what we relearned about weed control in 2005. Dry weather can make weed control more difficult, whether using soil-applied or postemergence herbicides. Applying a herbicide to a dry soil surface followed with no precipitation or mechanical incorporation for several weeks after application often provides numerous opportunities for applicators to survey the resulting weed populations on their customers fields. Relying on a total postemergence weed control program in corn and waiting too long to spray can (and does) reduce corn yields. Corn under stress is usually more likely to demonstrate enhanced injured by postemergence herbicides, whereas weeds under stress are generally more difficult to control. Glyphosate resistance has been documented in summer annual weed species in several states, and sooner or later it will be documented in Illinois.

# The Day After Yesterday

## Disease Management Issues in 2005, with Expectations for 2006

DEAN MALVICK

Looking back to the time when we looked forward to the 2005 cropping season, we can see a very different set of possibilities, ideas, and even predictions about crop diseases than we now know have come to pass. Perhaps the foremost example is soybean rust, a disease that was raising much anxiety and concern in January 2005. Many predictions suggested it could be a serious problem in 2005 and that we better be ready. Now looking back, we know it did not become a problem, although other diseases did cause problems. But the possibility looms that soybean rust, as well as other diseases, may have dramatic direct and indirect effects on soybean and corn production.

We can take at least two lessons from our current "day after" viewpoint. One is that we cannot predict plant disease with accuracy very far in advance. Another is "lets not put all of our (disease management) eggs in one basket," meaning that we should be vigilant and realistic in keeping an appropriate level of focus on management of multiple diseases that we know are common in Illinois. Several diseases affected yields and quality of the soybean and corn crop in 2005, but soybean rust was not one of them.

As usual, there were surprises with regard to soybean diseases in Illinois in 2005. First, was it truly a surprise t that soybean rust did not show up in Illinois? One can look at this from many points of view, but many things could have happened with soybean rust. The fact that it did not show up is a function of many factors, most of which are not clear, but they will become more clear over time. Foremost was that soybean rust did not seem to overwinter anywhere north of central Florida. Unfavorable weather conditions, i.e., dry and warm, also may have limited its spread northward. Alternatively, it could be that soybean rust will require two or more years to adapt and spread beyond the deep southern United States. There are many other factors that will become clear as we get more experience with soybean rust.

Weather conditions may have been a prime driver with regard to soybean rust as well as with other diseases. Soybean saw a host of disease problems that varied in intensity among fields and across Illinois. Sudden death syndrome (SDS) was significant in scattered fields, even though conditions were not what we generally think are most favorable for this disease.

Downy mildew was unusually common in much of the state, probably favored by high humidity and frequent dew. Septoria brown spot and charcoal rot developed, but probably not to the level that we may have predicted. Likewise, Cercospora leaf blight and frogeye leaf spot were more common in many areas than may have been expected. Another disease, brown stem rot, was also more severe than usual in parts of northern Illinois, which may have seemed unlikely based on the general weather conditions that so strongly influence this disease. Last, but not least, I mention the occurrence of stem canker and pod and stem blight, two diseases caused by closely related fungal pathogens that also periodically cause more damage than is widely recognized. The overall impact of all of these diseases in Illinois is difficult to quantify, but undoubtedly they are important causes of reduced yields, and perhaps reduced quality.

Corn yields were greatly affected by hot and dry conditions across much of Illinois. Along with these conditions came a relatively low incidence and severity of leaf diseases. In 2004, gray leaf spot, common rust, and

northern corn leaf blight were significant problems in some areas of Illinois, but these diseases were relatively minor in 2005. In contrast, drought conditions favored development of stalk rots, including anthracnose stalk rot, and ear rots in some areas. With the hot and dry weather patterns, Aspergillis ear rot and aflatoxin also became major concerns.

With each of these corn and soybean disease problems, weather conditions had major effects on their development. Looking back from "the day after" perspective makes this effect clear, but how can we best use our accumulating knowledge and experience as we look forward to soybean and corn disease management in 2006? In most cases, the best management practices are still based, in part, on the time-tested approaches of choosing appropriate varieties/hybrids, using optimal agronomic practices, and keeping track of and considering past problems in particular fields. For example, in areas where gray leaf spot occurs commonly on corn in low-lying fields, or Phytophthora rot occurs frequently in wet fields, balancing yield potential of a soybean variety with disease resistance is a sensible approach. Similarly, we cannot predict soybean rust yet, but the preparations and plans made for 2005 should be kept in mind and applied for 2006. Although uncertainties and challenges for crop disease management remain, the opportunities for improving disease management are vast and constantly increasing.

# The Day after Yesterday

## Have We Somehow Managed to "Drought-Proof" Crops?

EMERSON NAFZIGER

Dry weather started in Illinois in March 2005, and rainfall totals for March, April, May, June, and July were below normal for almost all areas of Illinois, putting us squarely in the 2005 "drought belt." One exception was that southern and parts of central Illinois had the remains of Hurricane Dennis move through during the second week of July, dropping several inches of rain in some places. But most of Illinois remained under drought—defined as less than 60% of normal rainfall over a period of 3 months—for much of the summer. Some parts of Illinois remained in drought status as fall began.

Even with what many considered to be a 1988-scale drought in their respective part of the state in 2005, corn and soybean yields were much higher in 2005 than in 1988. The August corn yield estimate from the National Agricultural Statistics Service (NASS) was 125 bushels per acre, which would have been the lowest yield in Illinois since 1995. That estimate increased to 136 bushels per acre in the September forecast and again to 145 bushels per acre in the October forecast. Soybean yield forecasts followed a similar trend, with the August forecast of 39 bushels per acre increasing to 41 bushels per acre in September and to 45 bushels per acre in October, which would make 2005 the third best soybean year in Illinois.

How did both crops survive, and even thrive, in a summer that will be remembered as hot and dry? For corn, I'd offer the following points:

- Planting was early and into relatively good soil conditions, although the soil in late March and early April might not have been as dry as it seemed. Although surface soils dried very well, the heavy equipment that we use in most fields caused compaction to a depth of 18 inches or more. Soils at that depth are usually at field capacity in the spring, when there are no crop roots to help extract water. Soils at field capacity compact readily.
- Although stands of early planted corn generally were good after seedling emergence, the frost of early May decreased the stands of some of the earliest-planted corn. Corn planted in mid April also suffered from wet soils and cooler temperatures during the last third of April, and soil crusting and other emergence problems were common. By mid-May, the condition of the corn crop was not great in many fields, but the crop was planted and most of it was up, on par with the fast start in 2004.
- Growing degree-day (GDD) accumulations were below average in May, and normal to above normal in June. By early to mid-June, the lack of rainfall was starting to show up in reduced growth and leaf curling in corn in the driest areas. However, the fact that soils were drying from the surface down kept root growth active at increasing depth. Roots can increase their length only in soils with enough water to allow this to happen; thus, root growth tends to slow in the surface soils as they dry out and to increase in deeper layers where enough water remains. Although we do not have a convenient way to measure this, the fact that the crop was able to keep growing in most fields was certainly because of unusually good root growth and root systems in the corn crop in 2005. Many of the more productive soils in Illinois hold as much as half of the 20 to 22 inches of water needed to produce a crop; and in 2005, we think that above-normal amounts of soil water were available because of the good root systems.

- Although GDD accumulation was at or above normal in July, tasseling and silking were slightly behind the pace we experienced in 2004. Part of this response was because of the warm temperatures in May 2004, but it is also likely that some "suspended growth" occurred in 2005. I use this term to refer to the accumulation of GDD without the normal amount of crop growth. At Urbana, the GDD accumulations for May and June were virtually identical in 2004 and 2005, yet the same hybrid planted both years at about the same time silked about a week later in 2005 than in 2004. Other pollination-time problems in 2005 included insect injury to silks and, in the driest fields, delay in silk emergence such that little pollen was available to complete the pollination process. Overall, though, the delay in development probably helped the crop in some fields, where rainfall later in July helped to improve kernel set.
- One of the accompaniments to dry weather is high solar radiation, and plentiful sunlight increases photosynthesis and plant growth. Temperatures were generally high during the summer, but night temperatures were moderated some by the low humidity (dew point), especially after early August. This is physiologically helpful, although it can't usually negate the effects of low photosynthesis under water stress.
- The weather during the second half of grainfill, after mid-August, was outstanding, almost as good as the weather during the same period in 2004. Much of the state received some rain in mid-August, temperatures decreased some, the sun shone, and the crop filled grain rapidly up to maturity. As a result, grain size and quality were good, the much-feared aflatoxin (produced by the *Aspergillus* fungus) failed to develop in most fields, and harvest started at the normal time, if not a little early.
- Even considering the fact that the negative of low rainfall early in the season was partly balanced by good roots, sunshine, low foliar disease pressure, and a favorable rainfall pattern late in the 2005 growing season, the fact that we managed to harvest good yields under such limited rainfall amounts still raises the question about whether modern corn hybrids are able to withstand dry conditions that would have ruined crops a few decades ago. The answer to this question is "yes." Higher corn plant populations tend to increase yield under good conditions, as long as standability is not compromised. This has led breeders to select hybrids under higher populations, with an emphasis on synchronization between silking and pollen shed, stalk strength and standability, competitive roots, and of course yield. Because high plant population is a stress condition, in which plants have to compete for light and water, the result of such selection has been hybrids that are more stress-tolerant than were earlier hybrids. This pays off in years like 2005.

We need to remember that 2005 was not a great year for many corn producers in Illinois, and that it was a very poor year for producers in the driest areas. Corn planted after corn tends to be a more stressful environment, so it probably suffered relatively more yield loss than corn planted after soybean. And, some producers who had fields declared total losses or who harvested less than 50 bushels per acre are less inclined to talk about this than those whose yields were higher than expected. All told, though, we dodged a bullet in 2005.

The case of soybean yields in the dry year of 2005 is a simpler story than the story of corn, and one with a happy ending for most producers in Illinois. Soybean planting was timely in the dry weather of May, and the crop escaped the cold early start that much of the corn crop experienced. Soybean plants benefited from favorable sunshine and good root systems. As in 2004 (and in contrast to 2003, a disaster year for soybean in Illinois), flowering started early in 2005, and podfilling was underway by late July in most fields. The rains in some places in July and in most places in August were even more helpful for soybean than for corn, and pods filled well.

Pod numbers were surprisingly high in many fields, after periods of weather in July and early August that were not conducive to good pod set. The good root system helped keep some water coming to the plant, but we also saw the unusual phenomenon of plants' increasing their height after the rains of mid-August. With the high temperatures and sunshine that followed these rains, many of the new pods produced harvestable seeds in a short time. More important than the additional yields from new pods was that the rain fell at a time when pod abortion was set to accelerate. Had it stayed dry for another week, pod numbers would have declined, and yields would have suffered.

# The Day After Yesterday

## Insect and Mite Management in 2005, with Expectations for 2006

KEVIN STEFFEY AND MIKE GRAY

Entomologists talk a lot about the many factors that affect insect pest populations during the growing season and over the winter. Usually, several factors, rather than a single factor, determine whether an insect population reaches densities of economic concern. Many inter-related factors significantly influenced the population dynamics and consequent impact of several insect and mite pests in corn and soybean in Illinois in 2005. Weather conditions during the 2005 growing season played a major, direct role in occurrences (or nonoccurrences) of economically threatening populations of insect and mite pests. The effects of weather and soil conditions (e.g., cool, dry soils early; hot, dry conditions throughout the summer) on crop development also influenced pest population dynamics and the impact of insect and mite infestations on crop yields. Moreover, the presence or absence of weeds, the presence or absence of natural enemies, and the effects of insect control products all played roles in the development of insect and mite populations in 2005. It is also likely that the populations of different pest species and their associated management tactics influenced one another. Consequently, separating the impact of one insect or mite species on corn or soybean yields from the impacts of other factors has been a challenge for producers, agribusiness professionals, and extension and research specialists.

This report is a synopsis of insect- and mite-management issues in Illinois and some other areas of the Midwest in 2005, with some explanations for what happened and some prognoses for 2006. We refer you to articles published throughout the year in *the Bulletin* (http://www.ipm.uiuc.edu/bulletin) for more detailed discussions of each of the issues described in this report. For ease of discussion, the synopsis is separated by crop, although some pests were present in more than one crop (e.g., Japanese beetle, twospotted spider mite, western corn rootworm).

### Insects and Corn Production, 2005

Although corn planting began at a record-early pace in Illinois in 2005, subsequent cool (occasionally cold) weather and dry or crusted soils were not conducive for corn growth. Emergence of corn seedlings was difficult and slow; corn plants grew slowly, if at all, for stretches of time; and corn stands were diminished. Some corn seedlings were killed by freezing temperatures. Because weak and slow-growing corn seedlings are more susceptible than healthy corn seedlings to injury caused by below-ground insect pests, we anticipated that white grubs, wireworms, and other subterranean insects would wreak havoc. As it turned out, however, we received fewer reports of injury caused by below-ground insects in 2005 than we had during the previous few years, although wireworms caused significant damage in some areas. So, most of the early season problems in corn production were directly related to the weather, rather than to the one-two punch of poor growing conditions and insect injury.

Early season cool weather was followed by warmer temperatures that, at first, seemed to be a blessing for crop development. However, the effects of a shortage of soil moisture became apparent in May. Corn root development was compromised by dry soil conditions, and questions about the performance of soil insecticides in dry soils began to arise, primarily regarding expectations for rootworm control with soil insecticides that had been applied in April.

At the end of May, we predicted a delayed hatch of corn rootworm larvae, based on the relatively slow accumulation of degree-days during the spring. However, by early June, when the potential for a drought in Illinois was looming, high temperatures sped up accumulation of degree-days, which seemed to compress rootworm larval hatch in time. Instead of the more typical gradual pattern of rootworm larval hatch, many larvae hatched during a brief period, signaling the rapid onset of injury to corn roots. Rootworm adults began to emerge somewhat early (mid-June) in many areas of the state. By the end of June, many people were reporting extremely large densities of western and northern corn rootworms. In the meantime, concern about dry soil conditions and poor performance of soil insecticides for rootworm control began to be realized.

Densities of western and northern corn rootworms were very large in 2005. Reports of excessive root pruning by rootworm larvae were common across much of Illinois. As expected, the effects of injury inflicted by corn rootworm larvae exacerbated the effects of the hot, dry weather that prevailed in many areas. Corn that was not protected against rootworm larvae showed signs of severe moisture stress in June and July, compared with corn that had an adequate level of protection against rootworm larvae. The combination of large numbers of rootworm larvae and a lack of moisture ultimately reduced corn yields in our experimental trials and in many cornfields. Research conducted near DeKalb, Momounth, and Urbana by Darren Bakken, a graduate student in the Department of Crop Sciences, revealed an interaction among less-than-adequate nitrogen (he examined several rates of application), severe rootworm larval injury, and lack of moisture. The results of these interactions were stunted plants and a poor canopy that enabled infestations of weeds to develop. At the time this report was written, the data from this study were being analyzed.

Although acres-treated data have not been tabulated yet, we suspect that more acres of corn were treated to control silk-feeding insects in 2005 than had been treated in many of the previous years. Drought conditions alone compromised pollination, and the appearance of large numbers of silk-feeding beetles (primarily western corn rootworms and Japanese beetles) escalated fears about poor pollination among corn producers. The static thresholds published for silk-clipping insects (five or more corn rootworm adults, three or more Japanese beetle adults) were not adequate for making unqualified decisions about their control. Modern research efforts to investigate the impact of silk-clipping insects on weather-stressed corn are sorely lacking.

The range of the variant western corn rootworm expanded into extreme western and into midsouthern counties in Illinois in 2005. As the range of the variant western corn rootworm expands, the use of rootworm control products will increase accordingly. Unfortunately, the use of yellow sticky traps to monitor for western corn rootworm adults in soybean fields falls far short of the effort needed to make well informed decisions about rootworm management.

Yet another "invasive" insect pest captured our attention in Illinois in 2005. Although only a few western bean cutworm moths were captured on one date in one county (Warren County) in Illinois in 2004, a network of pheromone traps in Illinois captured many western bean cutworm adults in July and August 2005. The largest numbers of western bean cutworms were captured in northwestern Illinois, but moths were captured as far east as Will County. These findings suggest that the western bean cutworm is becoming established as another pest of concern in corn production in Illinois. The western bean cutworm has spread very rapidly from western Iowa to eastern Illinois in only a few years, and scouting for the insect before larvae enter the ears has become a necessity in Iowa.

The "corn insect season" ended in 2005 with many reports of large densities of second-generation European corn borers, especially in western Illinois. Our annual fall survey of overwintering larvae revealed larger densities of this pest than had been recorded for several years, although overall densities were low compared with historic standards of economic infestations. Nevertheless, corn stalks weakened by drought conditions and stalk rot pathogens were further weakened by stalk-tunneling corn borers, resulting in significant lodging in some fields.

Finally, we received numerous reports in September and October of significant amounts of insect injury to corn ears. Because western bean cutworm is the newest arrival in Illinois, much of the injury was attributed to this pest. However, without observing the insect responsible for the injury, it is very difficult to distinguish among injuries caused by western bean cutworms, corn earworms, fall armyworms, and European corn borers. It is likely that much of the injury to corn ears attributed to the western bean cutworm in 2005 was caused by corn earworms, and some of the injury was caused by European corn borers and fall armyworms.

## Insects and Corn Production, 2006

Forecasting insect populations in corn is a practice fraught with uncertainty. The truth is that we rarely have enough information to be able to forecast insect populations in corn with a great deal of accuracy. However, some observations are worth mentioning.

***Corn rootworms.*** Because of the very dry soil conditions that prevailed during the time when corn rootworm adults were laying eggs (late July throughout August), oviposition (egg laying) most likely occurred in drought cracks. Eggs probably were laid deeper in the soil profile (in many instances 8 to 12 inches deep) in 2005 than during nondrought years, which may translate into a later larval hatch in 2006. Instead of larval hatch occurring in late May, much of the hatch may not begin until early June. A cool spring could delay corn rootworm larval hatch even more, which will challenge soil insecticides and some transgenic corn rootworm hybrids to adequately protect root systems, particularly if corn is planted in April.

It is also possible that the drought conditions had a negative impact on rootworm adult populations. In 1988, many corn rootworm adults died from septicemia (blood poisoning), resulting in fewer corn rootworm problems in 1989. The unanswered question is whether the adults died before or after they laid eggs in 2005.

The range of the variant western corn rootworm probably will expand somewhat in 2006, so corn producers in southern Illinois will have to become more familiar with rootworm management options. In 2006, corn growers in midsouthern counties should 1) assess the amount of corn root injury caused by rootworm larvae in fields of corn planted after soybean and 2) monitor for western corn rootworm adults in soybean fields in July and August.

***European corn borer.*** Densities of second-generation European corn borers in 2005 suggest the potential for greater-than-recent densities of first-generation corn borers in 2006, especially in western Illinois. However, time of planting and weather conditions during moth flights and larval establishment in 2006 will have a tremendous impact on the survival of these insects.

***Western bean cutworm.*** Western bean cutworms should be the target of scouting efforts in corn in Illinois in 2006, especially in the northern one-third of the state. Although the numbers of moths captured in Illinois in 2005 were far fewer than the numbers captured in Iowa, the mere presence of western bean cutworms across much of northern Illinois signifies a potential threat to corn production in 2006.

***Management of corn insects in 2006.*** The number of tools for insect control available to corn producers continues to increase. Many producers will continue to use soil-applied insecticides for control of soil-inhabiting insects, especially corn rootworm larvae, despite occurrences of poor performance of the insecticides linked to dry soil conditions in 2005. We also anticipate more widespread use of seed-applied insecticides (nicotinoids), whether or not their use can be economically justified in each field in which they are used. Nicotinoid seed treatments are largely effective against the early season subterranean insects, but their efficacy against corn rootworm larvae is not reliable when densities of rootworm larvae are large.

More corn acres will be planted to transgenic corn for rootworm control in 2006 than in previous years. YieldGard Rootworm corn hybrids and Herculex RW corn hybrids (the latter approved for use in the United States late in 2005) both will be planted in 2006. Although we still have much to learn about the use of transgenic corn for rootworm control, reports of its efficacy are mostly very positive. Nevertheless, some questions about the impact of transgenic corn on rootworm development and behavior linger. Incidents of significant injury to the roots of transgenic corn late in the summer (e.g., August) must be investigated.

YieldGard Corn Borer and Herculex I corn hybrids will provide protection against European and southwestern corn borers, and Herculex I will control western bean cutworms. Overall, it is very likely that more acres in Illinois will be planted to transgenic corn with insect control traits than in any year since the introduction of this technology. The implementation of insect resistance management strategies (e.g., planting of non-Bt corn refuges) should be a high priority for producers who choose to plant transgenic corn for insect management.

## Insects (and Mites) and Soybean Production, 2006

Since the discovery of the soybean aphid in the Midwest in 2000, soybean insect management has not been the same. This insect has captured our attention like no other insect pest in soybean in the Midwest.

Based upon the flight of soybean aphids in fall 2004 and information about their overwintering success, we had expectations for significant infestations of soybean aphids in 2005. Soybean aphids were discovered in Illinois soybean fields very early in 2005. And because drought-stressed soybean could be stressed even more

by infestations of soybean aphids, concern about this insect escalated in June. However, high temperatures throughout much of the summer were not conducive for the development of soybeans aphids, so they failed to establish large colonies in many fields. (Optimum temperatures for soybean aphid development are between the mid-70s and mid-80s degrees Fahrenheit). Although some very intense infestations occurred in localized areas, a widespread outbreak did not occur. Nevertheless, many soybean fields were sprayed for control of soybean aphids—some justified, some not justified.

Soybean aphid infestations in the northern Midwest were more widespread and economic than they were in Illinois. Matt O'Neal (2005) estimated that slightly more than 2 million acres of soybean in Iowa were treated for control of soybean aphids in 2005. Chris DiFonzo estimated that more than 90% of the soybean acres in Michigan were treated for control of soybean aphids (O'Neal 2005).

The most conspicuous natural enemy of soybean aphids is the predatory multicolored Asian lady beetle, which reduces the numbers of soybean aphids during the summer. Multicolored Asian lady beetles are most noticeable during years when soybean aphid populations reach outbreak proportions, so the lady beetles were common in 2005 in areas of Illinois where soybean aphids were numerous. The every-other-year cycle of soybean aphids (i.e., high densities one year, low densities the following year), thus far, may be largely because of the impact of multicolored Asian lady beetles.

After significant scares related to bean leaf beetles and bean pod mottle virus in 2001, 2002, and 2003, bean leaf beetles have not been much of a threat to soybean production recently. We received very few reports of bean leaf beetle activity in early planted soybean in 2005, and numbers of this insect pest remained low throughout most of the summer. However, it is worth noting that many people reported conspicuous numbers of bean leaf beetles in the fall as the beetles sought overwintering quarters.

The occurrence of twospotted spider mites when drought conditions prevail has been well documented, so their appearance in 2005 was not surprising. However, we had not witnessed such widespread infestations of spider mites in soybean in Illinois since 1988. People began spraying soybean fields or areas of soybean fields to control spider mites in some regions of the state in June, and miticide applications continued into August in the drought-stricken areas. Infestations of spider mites began to occur in Iowa and Wisconsin in mid-July. Miticide use data have not been compiled yet, but it is likely that more than 1 million acres of soybean were treated for spider mite control in Illinois in 2005. Many fields were treated more than once because mite densities resurged after the first miticide applications, and there were reports of fields being treated three or more times. Many people reported that second and third applications of miticides did not seem to be effective. Additionally, insecticide "cocktails" were applied for control of spider mites alone or in combination with other pests (e.g., soybean aphids and spider mites), with variable results. There was concern that fields sprayed with pyrethroid insecticides for control of soybean aphids would become infested with spider mites, which are not controlled by pyrethroids.

Spider mite infestations in many soybean fields in 2005 were linked with the growth of winter annual weeds on which the spider mites overwintered. For example, in a field near Tolono (Champaign County) where we conducted a miticide efficacy trial in 2005, the spider mites within the field seemed to have begun feeding on henbit (*Lamium amplexicaule*) in the spring before it was killed by Roundup herbicide. By the time Roundup was applied, the spider mites had already begun to flourish on the henbit. As the henbit began to die, the spider mites moved onto nearby soybean plants, and the rate of infestation accelerated throughout the field.

An estimate of the percentage of soybean acres sprayed with insecticides or miticides for control of soybean aphids, twospotted spider mites, or both is critical for our assessment of the importance of these two pests to soybean production in 2005. Without this information, the economic significance of soybean aphids and twospotted spider mites in Illinois cannot be determined.

## Insects and Soybean Production, 2006

Forecasting insect populations in soybean is just as risky as forecasting insect populations in corn. Nevertheless, we have some indicators that inform us slightly more than guesswork.

***Soybean aphid.*** Since 2001, the use of suction traps to capture flying soybean aphids has generated information that enables us to compare soybean aphid populations from year to year. The flight of soybean aphids in the fall may provide some insight into the potential for soybean aphid infestations the following year, with some qualifications. Through September 2005, numbers

of soybean aphids being captured in suction traps throughout the Midwest were not noticeably large. In addition, multicolored Asian lady beetles were plentiful in many areas in the fall. If the every-other-year cycle for soybean aphid densities holds, we should anticipate fewer soybean aphid problems in 2006 than we did in 2005. However, as we learned in 2005, weather plays an extremely important role in regulating soybean aphid populations. Consequently, only early season (June) scouting will provide prognostic evidence of soybean aphid infestations.

Although the multicolored Asian lady beetle garners the most attention as a natural enemy of soybean aphids, another, less-noticed predator may be just as important for regulating soybean aphid populations during some years. Entomologists at Purdue University have learned that the insidious flower bug, *Orius insidiosus*, is capable of regulating populations of soybean aphids early in the season (Yoo and O'Neil 2004). According to Yoo and O'Neil (2004), insidious flower bugs have certain characteristics that attract them to soybean fields even before soybean aphids are present. They attack many other insects, or alternative prey, before soybean aphids arrive. They also feed on soybean pollen and obtain moisture and minerals from soybean plants. Observations in Indiana have indicated that the later soybean aphids occur in fields after predators have arrived, the more effectively the predators seem to prevent aphid population growth. The presence of alternative prey in soybean early in the season may help to promote an abundance of minute pirate bugs. Early season scouting may reveal the presence or absence of insidious flower bugs and alternative prey, which might contribute to our ability to foretell the potential for the development of soybean aphid populations.

***Bean leaf beetle.*** Mild winter temperatures improve the survival of bean leaf beetles, so a mild winter (2005–2006) will raise concerns about bean leaf beetles in spring 2006, especially if weather and soil conditions allow for early planting. Mild winter temperatures and early planting of soybean would enable bean leaf beetles to become established to threaten soybean production for the rest of the year.

***Twospotted spider mite.*** Predicting twospotted spider mite infestations is almost the same as predicting the weather, i.e., if hot, dry conditions prevail again in 2006, twospotted spider mites will threaten soybean yields again. However, even if drought conditions recur in 2006, it is possible that control of winter annual weeds would delay the onset and potentially reduce the impact of spider mite infestations. An infestation of spider mites in a conventionally tilled soybean field developed much later in the season in 2005 than in the adjacent no-tillage soybean field in which we conducted our miticides efficacy experiment. Winter annual weeds had been controlled in the conventionally tilled field.

***Management of soybean insects, 2006.*** Managing insects and mites in soybean in Illinois typically has not included the prophylactic use of insect-control products that is common for management of corn insects (e.g., application of soil insecticides). However, the availability of seed-applied insecticides (nicotinoids) on soybean has sparked an interest in preventing infestations of bean leaf beetles and soybean aphids early in the season, so it is likely that use of this technology will increase. Additionally, application of a fungicide–insecticide mix, even in the absence of pests, has been promoted for the expectation of a yield benefit. The economic benefits and potential ecological effects of either of these preventive insect control measures have not been thoroughly examined.

Without argument from many people, the soybean aphid has become the number one insect pest of soybean in the Midwest. Even when population densities are low, virtually all soybean producers keep a watchful eye on the development of soybean aphids all season. The bean leaf beetle and concerns about its vectoring bean pod mottle virus affirm its "most-feared" status when beetle populations establish early. The very best preparation for both insects is early (shortly after planting for the bean leaf beetle, in June for the soybean aphid) and regular scouting to monitor their populations' activities. Widely accepted economic thresholds have been established for both insects. Timely application of an insecticide, if the density of either insect reaches the economic threshold, is the most consistently economically justifiable management tactic. The impact of seed-applied insecticides on management of bean leaf beetles and soybean aphids has yet to be fully explored.

## References

O'Neal, M. 2005. Insecticide use for soybean aphid control up again in 2005, pp. 199–200. *In* Integrated Crop Management, IC-494 (24), October 10.

Yoo, H. J., and B. O'Neil. 2004. The minute pirate bug: An important predator of soybean aphid. The New Agriculture Network, Vol. 1, No. 5, June 10. http://www.ipm.msu.edu/new-ag/issues04/06-10.htm#1, visited October 2005.

# Generating N Recommendations from Data

Emerson D. Nafziger

There has been a great deal of recent work on the response of corn yield to fertilizer nitrogen (N) rates. Much of this work has been stimulated by the need to provide a stronger basis for determining optimal economic rates of N application, and by the need to minimize environmental consequences of corn production. Most results of such work have shown a large amount of variability in N response (Nafziger et al. 2005). Such variability has led us to look for a new approach to using N rate data to formulate N use guidelines.

The variability in corn's response to N fertilizer has been confirmed in numerous studies dating back more than 50 years in Illinois. In the 1950s and 1960s, the variability in corn's response to N fertilizer was accommodated by recommendations that called for the use of N rates within a rather wide range. The 1971 *Illinois Agronomy Handbook* suggested using N rates "between 125 and 250 lb per acre" for corn following corn in Illinois. During the 1970s, the wide range of rates was narrowed by using the results of trials averaged over years, then calculating a factor that related N rate to yield, resulting in the "Yield Goal" or "Proven Yield" method. The current recommendation is to apply "no more than" 1.2 lb of N for each bushel of expected yield for corn following corn, with N credits given when corn follows a legume or when manure has been applied to the field (Hoeft and Peck 2002). One difficulty with this recommendation is that yields, and thus actual N requirement, cannot be predicted with accuracy. Still, this recommendation has worked well in most years and for most fields, especially when N costs have been relatively low compared with the corn price.

When the ratio of N cost to corn price is low, there is little economic penalty to setting the N rate relatively high, because the financial consequence of applying more N than the crop needs is relatively small. There are several difficulties, however, with this approach. First, corn yields have been very high in many Illinois fields in recent years, resulting in a rapid increase in "proven yield" in many fields, which in turn calls for increased N rates. With an expected yield of 200 bushels per acre, applying the 1.2 factor and subtracting the 40-lb N credit for soybean results in a suggested application rate of 200 lb N per acre. In only five of 40 site-years in one of our ongoing studies on N response of corn following soybean has the economically optimum N rate exceeded 200 lb N per acre, and the average has been only 132 lb N per acre. When we used a higher N cost to reflect recent price increases, the optimum N rate was at or above 200 lb N per acre in only two of these 40 site-years, and the average optimum rate was only 120 lb N per acre.

A second problem with the proven yield method when corn follows soybean is that recent research has shown that the correlation is very weak between yield and the N rate needed to reach that yield. In other words, the idea that expected yield is related to the N rate needed to reach that yield is not supported by research findings. This is not really surprising, because the proven yield method was developed by averaging research results over a number of trials (mostly corn following corn), finding the optimum N rate and the yield at that N rate, then dividing this N rate by this yield. This approach produced the factor of 1.1 to 1.2 lb N per bushel (depending on the N:corn price ratio) used to set N rates. The ratio we calculate using more recent data is often in this same range of 1.1 to 1.2 lb N per bushel that was calculated decades ago, at least

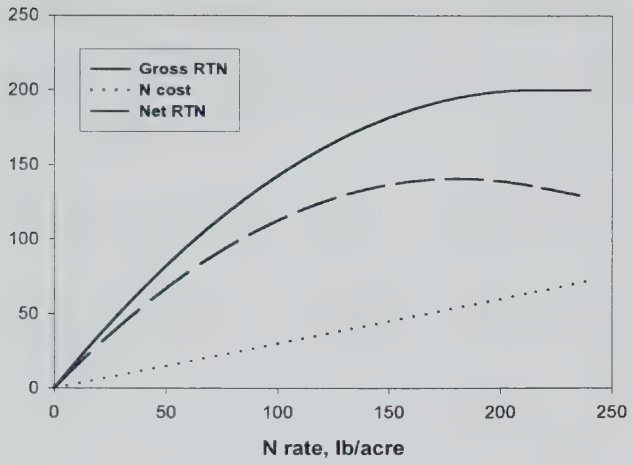



**Figure 1. Nitrogen cost and RTN lines applied to the data from a single N rate trial at Urbana, IL, in 2000.** The yield without N (baseline) was 124 bushels per acre. Costs and returns are based on N at $0.30 per lb and corn at $2.00 per bushel.

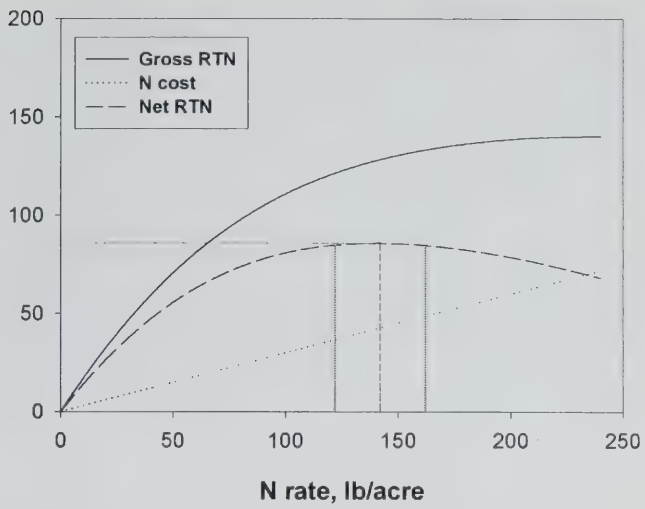



**Figure 2. Nitrogen cost and RTN averaged over 172 Illinois trials for corn following soybean.** Prices are as indicated for Figure 1. The MRTN point is $85.74 at an N rate of 142 lb per acre, indicated by the horizontal and vertical dashed lines. The N rates range within which the RTN is within $1.00 of the MRTN is 122 to 162 lb per acre, bounded by the vertical gray lines.

for corn following corn. Much of the earlier work was conducted on corn following corn, and there is more correlation between yield and the N rate needed to reach that yield in continuous corn than there is when corn follows soybean. Hence, the use of expected yield to suggest an appropriate N rate is more justifiable for corn following corn than for corn following soybean. Of course, we never know what actual yield will be, and that remains a large source of uncertainty.

For corn following soybean, even if we somehow knew what the yield was going to be, our results tell us that we would have little idea what N rate would be needed to get to that yield. As an example, in more than 40 separate trials in a study we are conducting, yields greater than 200 bushels per acre for corn following soybean have required, depending on the year and location, anywhere from 65 to 202 lb N per acre. In instances where yields were less than 130 bushels per acre, the N rate required to produce those yields has ranged from 34 to 180 lb N per acre.

Working with agronomists in other Corn Belt states, we have developed a new approach to making N rate guidelines (Sawyer and Nafziger 2005). This approach uses data from most of the recent N response work that has been conducted in Illinois, including results from both small plots and on-farm trials. The method involves calculating net return to N fertilizer (RTN) based on data from each trial, then averaging these returns (at each N rate increment) over appropriate trials.

To do this, we first fit a function to N rate response data from each trial. We used that function to calculate the yield increase from N, the gross return (yield increase multiplied by the price of corn), and the net return to N, or the gross return minus the N cost (rate multiplied by price) at each N rate. For the examples here, we will use an N price of $0.30 per lb and a corn price of $2.00 per bushel. Figure 1 shows the results of such calculations based on data from an N rate trial at Urbana in 2000, with yields replaced by dollars per acre, and the baseline set at the gross return (124 bushels × $2.00 per bushel = $248.00) without N.

To formulate N recommendations for Illinois, we calculated RTN at each N rate based on data from each N rate trial and then averaged the RTN values over all trials. The database we used consisted of results from 172 separate trials of corn following soybean, with a mixture of on-farm strip trials, small plot trials at research centers, and small plot trials in production fields. The average response over all of these trials is shown in Figure 2. In this example, I chose to use only the data from "responsive" trials, i.e., trials in which increasing the N rate increased yield. Most of the non-responsive sites in the Illinois database were from fields that had a history of manure application. As expected, such sites show much less return to N.

We use the "Net RTN" curve in Figure 2 as the basis for the N rate guidelines. There is a high point on this curve, which we call the maximum return to N, or MRTN. In this instance (Figure 2), the MRTN is $85.74 per acre, and it comes at an N rate of 142 lb N per acre. Note that this curve is relatively flat on top, indicating that the return to the investment in N is about the same over a range of N rates. We arbitrarily chose to set this range so that the RTN was within $1.00 of the MRTN. This N rate range is 122 to 162 lb N per acre, which, in this instance (Figure 2) is 20 lb of N on either side of the N rate that gives the MRTN. Based on this, we would set the N rate guideline for corn following soybean in Illinois at 122 to 162 lb N per acre.

This N rate range changes depending on the prices of corn and nitrogen. When the N price increases and corn price doesn't increase, the range shifts to lower N rates, at the rate of about 10 lb N for each 6-cent increase in the price of a pound of N ($100 more per ton of anhydrous ammonia). The range also gets narrow as N price increases, reflecting the fact that the financial penalty for being over or under the "best" N rate increases more quickly.

Why a range of suggested N rates, and how do you decide where to be within that range? N rate ranges are used as recommendations in several other states (including Iowa), and the ranges have become accepted there. However, the main reason we chose to use them was that the data indicate that returns to N are similar over a range of rates, so there is no real indication that we need to try to be more exact. We also recognize that N responses vary a lot over fields and years, and we have found no way to know how the crop will respond to N in a certain field before we have to decide what the N rate will be. A range also allows people to apply personal approaches to risk, and to find a rate with which they are comfortable, whether the rate is toward the middle of the range (a reasonable default number), on the high end because of experience or a landlord who demands that the crop "never be deficient," or toward the low end to better prevent movement of leftover nitrate into water, or as a fiscally conservative approach.

We have data to take a similar approach for corn following corn, although our database is not as large. Because corn following corn usually yields less without N fertilizer than corn following soybean, the gross and net returns to N application in corn, after subtracting the baseline of yield without N, is usually greater for corn following corn. Using our database of 82 trials for corn following corn and the same prices as we used in the examples for corn following soybean, the MRTN for corn following corn is $106.49 per acre, and this occurs at an N rate of 156 lb N per acre. Yield at this N rate is 148 bushels per acre. The RTN is within $1.00 per acre of the MRTN over the range of 137 to 174 lb N per acre.

These numbers are only about 15 lb N per acre more than the numbers for corn following soybean. What happened to the 40-lb "soybean N credit"? When we do these studies in the same trial in the same field, the difference in the N rate needed to maximize RTN is about 40 lb N on average. The main reason we see a smaller difference is because many of the trials we have included in the database come from different fields, so the comparison is less controlled. It is also possible that corn following corn tends to be in fields of higher productivity, in which the N supply from soil organic matter might be larger, so the need for fertilizer N might be less. Such a difference might be detected in field trials, but not in side-by-side trials.

Besides the need for higher N at lower yield levels, corn following corn also differs from corn following soybean in an important way: When corn follows corn, there is a relationship between yield and the N rate it takes to reach that yield. This relationship is not especially strong—we get the same variation due to soil, crop, and weather patterns as we do when corn follows soybean. But the relationship is significant, meaning that it is not due just to chance. If we look at the results from all 82 corn-following-corn trials in our database, we find that the optimum N rate increases by about 0.4 lb for each bushel of increase in yield, starting at about 100 bushels per acre.

One reasonable way to use this information is to subtract the 148 bushels per acre (the yield at the MRTN mentioned previously) from the yield we expect to obtain, multiply this difference by 0.4 lb N per bushel, and add (or subtract, if we expect less than 148 bushels per acre) this amount of N to the N rate at the MRTN (156 lb N per acre in this instance) as a way to adjust N rate within the suggested range.

Expected yield is best estimated by averaging yields over the past five seasons in a field, but in this instance, averages need to be determined from the yields of corn following corn. If corn has not followed corn in the field, or has done so only once or twice, then producers should use the yield average for corn following soybean in the field and subtract 10%. As an example, if the yield average for corn following soybean in a field is 190 bushels per acre, a producer should use 171 bushels

per acre as the expected yield when corn follows corn in that field. Subtracting 148 gives a difference of 23 bushels, which would give an adjustment of 23 × 0.4 = 9 lb of additional N. That may not seem like much, and it is still possible to use more N and stay within the range, but using expected yield to "nudge" the N rate up or down is justified by the fact that higher yields of corn following corn needs a little more N.

One of the useful features of the approach of determining N rate explained herein is that we can use the database as it exists, but we also can easily add data as we it is generated from more N response trials. How many trials do we need to run before we can "know" what N rates should be? We already know that N responses are always going to be variable, and our approach tries to deal with that variability, rather than to use single numbers as recommended N rates. Although we appreciate efforts to find ways that predict what the N response will be in a particular field before the crop starts to grow there, we are not optimistic that this will happen. The only other way to deal with this is to generate enough data so that fields in Illinois, or in each region of Illinois, are well represented in the trials that we conduct. This will take hundreds of trials, but in the end we will have a database that allows us to make N rate suggestions with much more confidence than we have been able to manage up to now.

## References

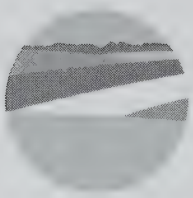

Hoeft, R. G., and T. R. Peck. 2002. Soil testing and fertility, pp. 91–131. *In* Illinois Agronomy Handbook, 23rd ed. University of Illinois Extension, College of ACES, University of Illinois at Urbana-Champaign.

Nafziger, E. D., R. G. Hoeft, E. Adee, R. E. Dunker, S. A. Ebelhar, and L. E. Paul. 2005. Assessing variability in corn response to N rate, pp. 12–18. *In* Proceedings of the Illinois Fertilizer Conference, January 24–26, Peoria, IL.

Sawyer, J. E., and E. D. Nafziger. 2005. Regional approach to making nitrogen fertilizer rate decisions for corn. Proceedings of the North Central Extension-Industry Soil Fertility Conference, November 16–17, Des Moines, IA.

# Worldwide Nutrient Supply and Market Update

Mark Nordwald



# Understanding N Loss Mechanisms and Improving N Use Efficiency

G. J. Schwab

Many corn and wheat producers are feeling pinched between high nitrogen (N) prices and low commodity prices. High fertilizer prices are a result of the soaring cost of fossil fuels (used in the manufacturing process), high transportation costs, and an ever-increasing worldwide demand for fertilizers. In the past, fertilizer was a relatively small part of production expenses, so university personnel responsible for writing recommendations preferred to err on the side of over-fertilization, rather than risk yield loss associated with under-fertilization. Of course, today the cost of over-fertilization is much higher; which leads many producers to wonder how much nitrogen they really need for their specific growing conditions.

## Historical Background

University fertilizer recommendations are formulated based on research results over a wide range of climatic and agronomic growing conditions. The results are pooled into groups with similar production practices (e.g., all studies with a previous crop of soybean) and summarized. Statisticians then examine the data to find the probability of crop response in each production system, whereas economists scrutinize the data for the economical threshold. Agronomists look for trends among fields with similar cropping histories, soil types, drainage, and so on. Although everyone has a different way of looking at the data, the end result is the same: an educated guess at the nitrogen requirement of a particular crop in a given year. A compounding factor is that most fields are not homogeneous, so the most efficient rate in one area may not be correct in another. Some of the factors determining the N requirements of the crop are known before it is planted, but ultimately, weather conditions during the growing season are the main factor for growers without the benefit of irrigation.

Nitrogen use efficiency (NUE) is a term used to describe the amount of applied fertilizer N that is taken up by a crop. Surprisingly, NUE is usually less than 50%, meaning that more than half of the fertilizer N is either lost or stored in the soil for future crops. Much of this inefficiency is a result of applying more N than the crop actually needs. For example, if a particular cornfield needs 150 lb N/acre, but the producer applies 200 lb N/acre, then 50 lb (25%) of the nitrogen was wasted by over-application alone. Entire scientific careers have been spent determining the appropriate rate of N fertilization, but the focus of this report is to discuss one of the underlying assumptions within nitrogen recommendations.

Every time we apply N to the soil there is a portion that is lost. The amount lost is a function of many things, including soil properties, application method, application timing, and specific fertilizer used. When making fertilizer recommendations, we assume there will be "average" N loss. By understanding the N-loss mechanisms in specific production systems, grain producers can manipulate N fertilization to bring losses to below-"average" levels. Implementing changes in production practices to reduce N loss will improve NUE and reduce the total amount of N required to obtain maximum yields.

## Understanding N Loss

The first step to improving NUE is to thoroughly understand N loss mechanisms. Nitrogen loss refers

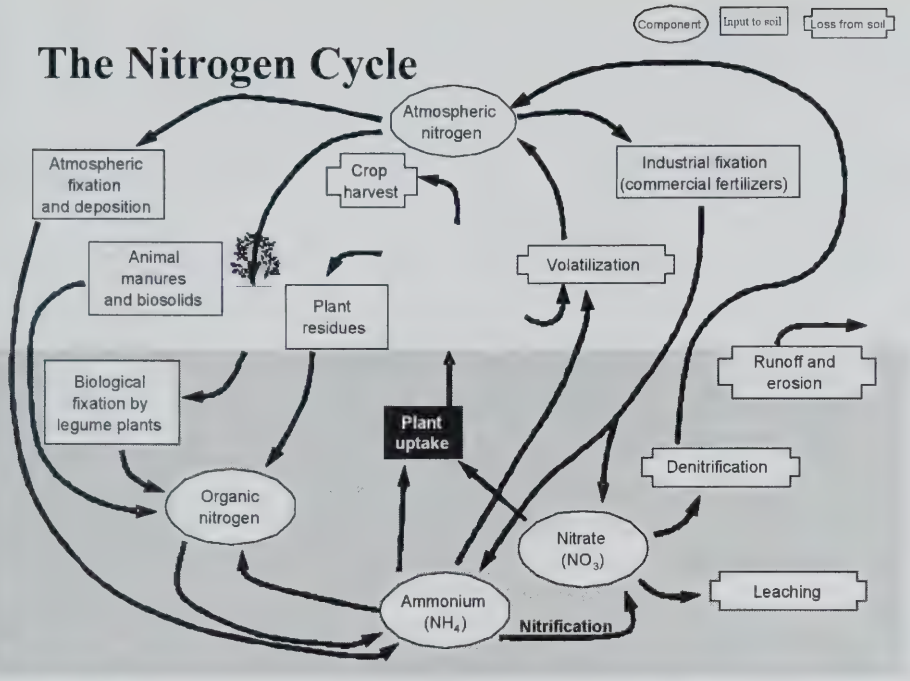



**Figure 1. The nitrogen cycle, showing components, inputs, losses, and transformations to soil nitrogen pools (reproduced with permission from The Potash and Phosphate Institute).**

to nitrogen that was once plant available but is now unavailable to the plant due to either N leaching below the rooting zone or N being converted back into atmospheric gas. Figure 1 is a diagram of the nitrogen cycle. At first glance, it looks very confusing, but if it is broken down into components, it is actually pretty simple. Keep in mind your goal is to supply the needed amount of N to the crop and minimize N loss. Nitrogen taken up by plants must be in one of two inorganic forms in the soil: nitrate ($NO_3^-$) or ammonium ($NH_4^+$). Unfortunately, these are also the forms susceptible to loss. In the N cycle, there are three main loss mechanisms: nitrate leaching, denitrification, and ammonium volatilization.

## Nitrate Nitrogen Loss

When discussing N loss, most people quickly think of $NO_3$! leaching due to the negative health implications and environmental impacts. **Leaching** is when $NO_3$-N is transported deeper into the soil profile by percolating water. Both the nitrate molecule and soil clay particles have negative electrical charges and therefore, repel each other. Because the clay does not hold $NO_3^-$, the molecule is free to move with the soil water. In regions such as Illinois where rainfall exceeds the water demands of the plant, nitrates can be leached through the profile and into tile drains or ground water, making it unavailable for plant uptake.

A second and probably more important loss mechanism affecting nitrogen availability is denitrification. **Denitrification** occurs when $NO_3$-N is converted into a gas and escapes back into the atmosphere. This reaction only happens when the soil is largely water saturated and has a low oxygen concentration. Depending on the amount of oxygen in the soil, the gas emitted is either in the nitrous oxide or nitrogen gas form. Nitrous oxide is considered a greenhouse gas, and emissions may be subjected to future environmental regulations. Denitrification losses are most common on poorly drained soils saturated for many days during the spring.

## Preventing Nitrate Loss

Remember that nitrate nitrogen is the only N form that is susceptible to leaching and denitrification losses, and both mechanisms require excessive soil moisture. With an understanding of these factors, we can begin to consider options for reducing loss. The main issue is the time of year fertilizer is being applied. Because denitrification occurs primarily when the soil is water saturated, losses are highest for N applied in the fall or early spring. Later side-dress applications usually result in very little denitrification loss because soil saturation is less likely and plant uptake is much quicker. The total amount of nitrogen lost is a function of the number of days the soil remains saturated and the amount of nitrogen in the $NO_3$-N form (Table 1). Also in Table 1, notice how the source of N fertilizer applied affects the total amount of N that is in the $NO_3$-N form. When you apply anhydrous ammonia or urea, soil microbes convert them into the nitrate form, which requires some time. In contrast, 25% of the N in urea ammonium nitrate is already in the nitrate form when it is applied. If the soil becomes saturated,

**Table 1. Percentage of fertilizer N in the $NO_3$-N form at 0, 3, and 6 wk after application**

| N source | Wk after application | | |
|---|---|---|---|
| | 0 | 3 | 6 |
| | % of fertilizer as $NO_3$-N | | |
| Anhydrous ammonia (AA) | 0 | 20 | 65 |
| AA with N-Serve | 0 | 10 | 50 |
| Urea | 0 | 50 | 75 |
| Urea with N-Serve | 0 | 30 | 70 |
| UAN solutions | 25 | 60 | 80 |
| Ammonium nitrate | 50 | 80 | 90 |

approximately 3 to 4% of the $NO_3$-N can be lost per day (after the second day).

If the N must be applied early, a nitrification inhibitor might be beneficial. **Nitrification inhibitors** slow the conversion of ammonium nitrogen ($NH_4$-N) to nitrate nitrogen ($NO_3$-N) in the soil (Figure 1). Depending on soil conditions, some inhibitors can slow this process by a few weeks (Table 1). The most common nitrification inhibitor, nitrapyrin (N-Serve®), has been commercially available for 30 years. It can be used with any N fertilizer that contains or produces (when applied to the soil) $NH_4$-N. Examples are anhydrous ammonia, urea, and urea-ammonium nitrate (UAN) solutions. Inhibiting nitrification is important because nitrogen in the $NH_4$-N form is held tightly by the soil particles and is not subject to leaching or denitrification loss.

Nitrification inhibitors have been effective for corn when N fertilizers were applied preplant at yield-limiting rates. In a study conducted in Bath, Lewis, and Lee counties in Kentucky, corn yield was increased by an average of 32 bu/acre when nitrapyrin (nitrification inhibitor) was applied with 75 lb N/acre as ammonium nitrate at planting (Frye et al. 1981). However, this study showed no significant yield increase with nitrapyrin at the 150 lb N/acre rate. These results demonstrate the need to reduce N application rates to get the benefit of the inhibitor. In general, Kentucky research has found economic benefits to nitrification inhibitors are more likely on poorly drained soils that tend to remain wet during the spring and early summer.

## Ammonia Volatilization

When urea fertilizers are applied to the soil, an enzyme called urease begins a conversion to ammonia gas. If this conversion takes place below the soil surface, the ammonia is almost instantaneously converted to $NH_4$-N, which is bound to soil particles. If the conversion takes place on the soil surface or on surface residues, there is a potential for the ammonia gas to escape back into the atmosphere. This process is called **ammonia volatilization**.

Volatilization losses depend on the environmental conditions at the time of application. Losses due to volatilization are highest when the soil is warm (above 50°F), experiencing high evaporation rates, or when pH is greater than 7. In most years, temperatures become high enough to cause concern in early May. After this time, urea N contained in surface applications is more volatile. If the fertilizer is surface applied and incorporated, or 0.25 inch or more rain is received within a few days, volatilization losses will be minimal. If, in contrast, the fertilizer is not incorporated and no rain is received, losses can exceed 25%, with an average of ≈10% of the total. High surface residue levels also increase volatilization; therefore, maximum losses will be observed when urea is broadcast on no-tillage or pasture fields after 1 May.

Volatilization losses can be substantially reduced if a urease inhibitor is used with the fertilizer. The most common urease inhibitor is NBPT [N-(*n*-butyl) thiophosphoric triamide], sold under the trade name Agrotain®. Urease inhibitors reduce the activity of the urease enzyme for up to 14 days. Rain is necessary during this 14-day period for the urea to be moved into

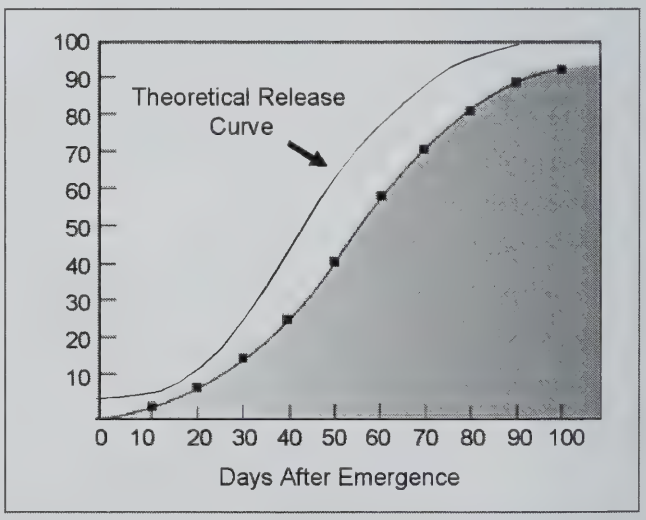



**Figure 2. Typical nitrogen uptake curve for corn, and a theoretical polymer coated urea release curve.**

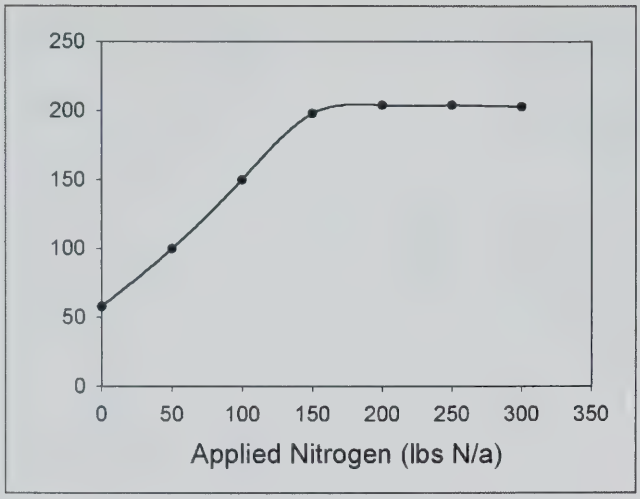



**Figure 3. Typical nitrogen response curve for corn grown on well-drained soils in Kentucky.**

the soil where it can be converted to $NH_4$-N. This will minimize the risk of volatilization.

## Controlled Release Urea

Controlled release fertilizer products also have been available for more than 30 years. Probably the best known of these products is sulfur-coated urea. A sulfur coating is applied to urea granules and urea dissolves/diffuses through imperfections in the coating. By altering the thickness and number of imperfections in the coating, release characteristics can be controlled. Sulfur-coated urea was not a useful agronomic product, in part, because the cost of coating was high relative to the cost of the N fertilizer.

Recent advances in polymer (plastic) technology have created a whole new type of controlled release fertilizer, the most common of which is **polymer coated urea** (PCU). Polymer coated urea has been used in the turf and horticultural industries for several years, but the cost of the materials prohibited their greater use in the agricultural market. Now Agrium Inc. has introduced a PCU called ESN® that is priced more competitively in the agricultural market. Modern polymers allow chemists to create release curves that closely match the uptake characteristics of target crops (Figure 2). The amount and rate of release is controlled by the thickness and other characteristics of the polymer.

## Changing Practices to Improve NUE

As alluded to previously, there are several factors to be considered before deciding whether changing N application practices would be economical in your specific production system. Ideally, corn producers should strive to apply just enough N to reach the maximum yield (≈150 lb N/acre for the data in Figure 3). If a farmer changes an N application practice (applies later or uses an inhibitor) but does not reduce the amount of applied fertilizer, yield will not be increased. The lack of yield response is apparent, because maximum yield has already been obtained. For these practices and products to be agronomically useful, the producer must reduce the rate of applied nitrogen by the amount of N he or she expects to save. If you can reduce fertilizer application rates without affecting yield, you have successfully improved NUE. To be economical, though, the price of the saved N must exceed the additional costs associated with the change.

## References

Frye, W.W., R.L. Blevins, L.W. Murdock, K.L. Wells, and J.H. Ellis. 1981. Effectiveness of nitrapyrin with surface-applied fertilizer nitrogen in no-tillage corn. Agronomy Journal 73: 287–289.

Frye, W.W., L.W. Murdock, and R.L. Blevins. 1990. Urease inhibitor reduces ammonia loss from surface-applied urea. Soil Science News and Views 11(8).

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# Glyphosate-Resistant Weeds—A Global Perspective

Ian Heap

Herbicide resistance is the evolved capacity of a previously herbicide-susceptible weed population to withstand a herbicide and complete its life cycle when the herbicide is used at its normal rate in an agricultural situation (Heap and Lebaron 2001). The first well-documented case of herbicide resistance was triazine-resistant common groundsel (*Senecio vulgaris*) found in a nursery in Olympia, WA (Ryan 1970).

Most cases of herbicide resistance have occurred because of the repeated use of the same herbicide/herbicide mode of action in minimum tillage systems where herbicides have been relied upon for high levels of weed control. Resistance risk factors associated with a herbicide include the mode of action of the herbicide, the efficacy of the herbicide, the frequency of its use, the number of years that it has been used, the area treated by the herbicide, and the number of species that it controls.

Herbicide mode of action is one of the greatest variables in the rate of evolution of resistance (Figures 1 and 2). It is clear from Figures 1 and 2 that weeds evolve resistance to acetolactate synthase (ALS) inhibitors, triazines, and ACCase inhibitors more rapidly than they do to synthetic auxins and glycines. There are many viable point site mutations that can confer resistance to ALS and ACCase inhibitors but few to 2,4-D or glyphosate.

Despite that glyphosate has been used on a large number of acres for more than 30 years and it controls more weed species than any other herbicide, only eight weed species have evolved resistance to glyphosate. This indicates that viable mutations conferring glyphosate resistance are very rare.

Glyphosate was introduced more than 30 years ago as a nonselective herbicide and is now the most successful herbicide ever patented. Its initial expense limited its use to applications on industrial sites, railways, roadsides, and in orchards. As its expense decreased, its use increased in broad-acre agriculture primarily as a tool in no-tillage and minimum tillage systems for weed control before crop emergence. The use of glyphosate then skyrocketed with the rapid adoption of Roundup-Ready crops in the mid- to late 1990s. The introduction of Roundup Ready crops has been beneficial in reducing the number of ALS, ACCase, and

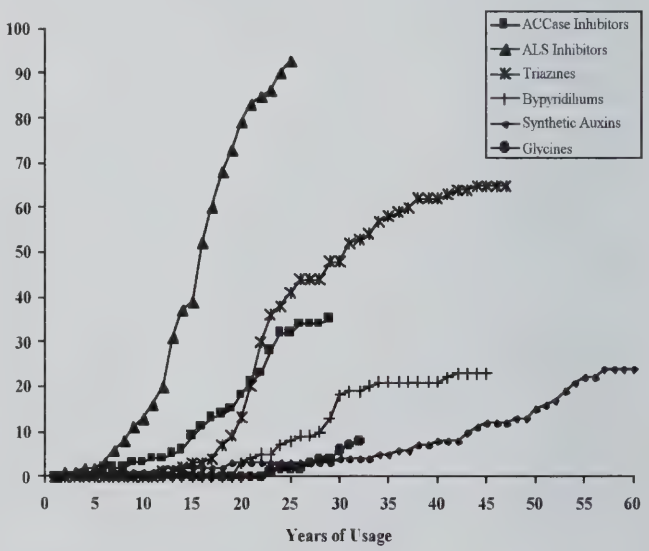



**Figure 1. The number of herbicide-resistant weed species in relation to the years of use of a herbicide mode of action globally.**

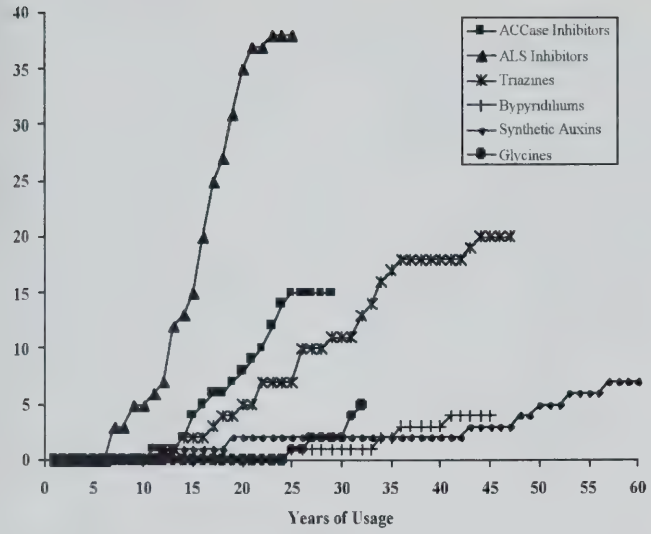



**Figure 2. The number of herbicide-resistant weed species in relation to the years of usage of a herbicide mode of action in the United States.**

triazine-resistant weeds reported in the past 6 years (Figure 2). However, the introduction of Roundup Ready crops has greatly increased the number of acres treated and the frequency of glyphosate use, which will increase the number of glyphosate-resistant weeds identified. Of the eight glyphosate-resistant weed species, five occur in the United States and three have been found in Roundup Ready cropping systems (Table 1).

## Rigid Ryegrass (*Lolium rigidum*)

It is a little ironic that the first glyphosate-resistant weed was identified in 1996, the same year that the first Roundup Ready crop (soybean) was commercially available. The two events were, of course, completely unrelated because the first glyphosate-resistant weed was rigid ryegrass found in an apple orchard in Australia in 1996 (Pratley et al. 1996, 1999). Rigid ryegrass is extremely adaptable and has evolved resistance to more than nine herbicide modes of action (Heap and Knight 1986, Holtum and Powles 1991). Since then, more than 40 populations of glyphosate-resistant rigid ryegrass have been identified in Australia, some also in orchards, but others in wheat cropping systems. The common factor in each case is that glyphosate had been used for 12 or more applications. Further glyphosate-resistant rigid ryegrass populations have been found in vineyards in South Africa and in orchards in California, again, after repeated use of glyphosate over a long time. Populations have varied to some degree in their level of resistance, but in general they were found to have an 8- to 12-fold increase in the level of resistance. Resistance has been attributed to decreased translocation (Feng et al. 1999) and is inherited by a single incompletely dominant gene (Lorraine-Colwill et al. 1999).

## Italian Ryegrass (*Lolium multiflorum*)

After finding more than 40 populations of *Lolium rigidum* with resistance to glyphosate, it was not that surprising to find populations of *L. multiflorum* with glyphosate resistance. Indeed, these two species are genetically very similar and freely cross, some argue whether they should even be considered separate species. The first populations of glyphosate-resistant Italian ryegrass were found in vineyards in Chile (2001), and then in orchards in Brazil and Oregon (Heap 2005).

**Table 1. Confirmed glyphosate-resistant weeds globally (as of November, 2005)**

| Species | Year | Location |
|---|---|---|
| Rigid Ryegrass (*Lolium rigidum*) | 1996 | Australia, United States, South Africa |
| Goosegrass (*Eleusine indica*) | 1997 | Malaysia |
| Horseweed (*Conyza canadensis*) | 2000 | United States |
| Italian Ryegrass (*Lolium multiflorum*) | 2001 | Chile, Brazil, United States |
| Hairy Fleabane (*Conyza bonariensis*) | 2003 | South Africa, Spain |
| Buckhorn Plantain (*Plantago lanceolata*) | 2003 | South Africa |
| Common Ragweed (*Ambrosia artemisiifolia*) | 2004 | United States |
| Palmer Amaranth (*Amaranthus palmeri*) | 2005 | United States |

The levels of resistance are even lower than that found in rigid ryegrass, about 4- to 8-fold.

## Goosegrass (*Eleusine indica*)

In 1997, glyphosate-resistant goosegrass from Malaysia was identified in orchards (Tran et al. 1999, Lee and Ngim 2000). Growers were applying more than six applications of glyphosate per year and under the warm environment goosegrass would go through three generations a year—in short, a recipe for resistance. The level of resistance is very low, about 3- to 4-fold. Compared with susceptible populations, the glyphosate-resistant goosegrass was found to have similar glyphosate uptake and translocation, and neither population metabolized glyphosate. Glyphosate inhibits 5-enolpyruvylshikimate-3-phosphate (EPSP) synthase enzyme in the aromatic amino acid biosynthesis pathway (shikimate pathway) (Devine et al. 1993). Resistance was found to be target site based because of a mutation in the EPSP synthase gene. The EPSP synthase enzyme in the resistant plants was 5-fold less sensitive to glyphosate. Like rigid ryegrass, the resistance was found to be inherited by a single incompletely dominant gene. In addition to glyphosate resistance, some populations also were found to be resistant to ACCase inhibitor herbicides such as fluazifop-p-butyl (Lee and Ngim 2000).

## Horseweed (*Conyza canadensis*)

The most widespread, and to date the most important, glyphosate-resistant weed is horseweed. In 2000 glyphosate-resistant horseweed was first identified in Roundup Ready soybean fields in Delaware (VanGessel 2001) and has since been found in 11 additional states and on an estimated 500,000 acres (Heap 2005). Glyhphosate-resistant horseweed populations exhibit an 8- to 12 fold increase in resistance. The mechanism of resistance is thought to be based on differences in translocation or sequestration between glyphosate-resistant and -susceptible horseweed populations. Resistance is conferred by a nuclear-encoded dominant allele (Heck et al. 2002).

## Hairy Fleabane (*Conyza bonariensis*)

Hairy fleabane is a close relative to that of horseweed and thus the discovery of resistance did not come as a complete surprise. Glyphosate-resistant hairy fleabane was first identified in vineyards in South Africa and the resistance seems to be similar to that found in horseweed, about 8- to 12-fold. Little work has been done on genetics or mechanism of resistance.

**Table 2. The most important herbicide-resistant weed species worldwide**

| | Common name | Species |
|---|---|---|
| **1** | **Rigid Ryegrass** | ***Lolium rigidum*** |
| 2 | Wild oat | *Avena fatua* |
| 3 | Redroot pPigweed | *Amaranthus retroflexus* |
| 4 | Common lambsquarters | *Chenopodium album* |
| 5 | Green fFoxtail | *Setaria viridis* |
| 6 | Barnyardgrass | *Echinochloa crus-galli* |
| **7** | **Goosegrass** | ***Eleusine indica*** |
| 8 | Kochia | *Kochia scoparia* |
| **9** | **Horseweed** | ***Conyza canadensis*** |
| 10 | Smooth pigweed | *Amaranthus hybridus* |
| 11 | Common groundsel | *Senecio vulgaris* |
| 12 | Smooth pigweed | *Amaranthus hybridus* |
| 13 | Annual bluegrass | *Poa annua* |
| 14 | Blackgrass | *Alopecurus myosuroides* |
| 15 | Black nightshade | *Solanum nigrum* |
| **16** | **Italian ryegrass** | ***Lolium multiflorum*** |
| 17 | Common waterhemp | *Amaranthus rudis* |
| **18** | **Common ragweed** | ***Ambrosia artemisiifolia*** |
| 19 | Prostrate pigweed | *Amaranthus blitoides* |
| **20** | **Powell amaranth** | ***Amaranthus powellii*** |

## Buckhorn Plantain (*Plantago lanceolata*)

Buckhorn plantain also was discovered in vineyards in South Africa, again by Dr. Andrew Cairns. Levels of resistance fell between 8- to 12-fold. Little else is known about this case at present.

## Common Ragweed (*Ambrosia artemisiifolia*)

Glyphosate-resistant common ragweed was identified in a Roundup Ready soybean field in Missouri in 2004 (Reid Smeda, personal communication, 2004). Reid Smeda and others are conducting a wide range of experiments, from the field to the laboratory on this

biotype. Resistance levels seem to be more than 10-fold. They are also attempting to reduce the spread of the population from the initial 20-acre infestation.

## Palmer Amaranth (*Amaranthus palmeri*)

The most recent glyphosate-resistant weed discovery is that of Palmer amaranth found in Roundup Ready cotton fields in central Georgia (Stanley Culpepper, personal communication, 2005). The dose-response data and heritability work have been completed, and the population was listed in September 2005. Work is underway on the agronomy, genetics, and mechanism of resistance.

## Confirmation of Resistance

The level of resistance found in each case is relatively low, compared with the levels of resistance found for target site resistance in triazine, ALS inhibitor, and ACCase inhibitor-resistant weeds. The level of glyphosate-resistance found in goosegrass was the lowest, the one case known to be target site based. These low levels of resistance have created a greater focus on the definition of herbicide resistance and the criteria that we use to decide whether a weed should be classified as resistant. To this end, a publication has been posted online entitled "Criteria for Confirmation of Herbicide-Resistant Weeds" at http://www.weedscience.org. There are also many rumors in the United States about glyphosate-resistant weeds that are not currently listed. Examples are common lambsquarters (*Chenopodium album*), waterhemp (*Amaranthus rudis*), and giant ragweed (*Ambrosia trifida*). Some of these weeds may eventually be listed as glyphosate-resistant; however, at present there is insufficient data to list them based on the "Criteria for Confirmation of Herbicide-Resistant Weeds."

## Future Cases

The International Survey of Herbicide-Resistant Weeds ranks resistant weeds based on the area they infest, the number of herbicide modes of action to which they have evolved resistance, the number of countries in which they occur, the number of cropping regimes in which they occur, and several other factors. Based on this ranking, Table 2 presents the worst or the "most important" herbicide-resistant weeds globally. It is interesting to note that six of the eight known glyphosate-resistant weeds occur in the top 20 most important herbicide-resistant weed species worldwide. This list, so far, has been the best predictor of which weeds will evolve resistance to glyphosate.

## Spread of Resistance

Because the initial frequency of glyphosate-resistant mutations in weed populations is extremely low, it will be more important to prevent the spread of resistant populations once they occur. For ALS and ACCase inhibitor herbicides, many farmers selected their own resistant populations within 7 to 12 years of use. Spread of resistance certainly occurred, but it was not a major issue because resistant individuals were likely already present on farmers' properties before any herbicide use. This is not necessarily the case for glyphosate-resistant weeds. The appearance of glyphosate resistance will be rare "per unit area treated" so it will be important to prevent their spread once resistance is detected. The biggest problems will be presented by those weeds that have excellent dispersal mechanisms, such as *Conyza canadensis*. In such cases, the prevention of spread is impractical. However for the recently discovered glyphosate-resistant *Ambrosia artemisiifolia* in Missouri there is merit in attempting to contain and delay its spread to other regions.

## Multiple Resistance—The Real Danger to Sustainable Weed Control

With the increased use pattern of glyphosate, there is no doubt that we will see an increase in the number of glyphosate-resistant weeds. What is in debate at present is how soon and to what extent glyphosate-resistant weeds will impact crop production here in the mid-west and does it make economic sense to adopt resistance management strategies to delay the appearance of glyphosate resistance.

Although a glyphosate-resistant weed may increase the cost of weed control and increase the management required, it is likely to still be manageable if the weed has only evolved resistance to glyphosate. After all, excellent weed control programs existed before Roundup Ready crops. Growers will continue to use glyphosate and add in additional herbicides to pick up the glyphosate-resistant weeds. The real danger to sustainable weed control is multiple herbicide resistance in a weed population. Unfortunately, this situation is exactly what is likely to occur, and to some extent has already occurred in horseweed. It has been pointed out above that herbicide mode of action greatly influences the speed that weeds evolve resistance to herbicides,

and equally importantly is that weed species vary considerably in their propensity to evolve herbicide resistance. The weed species that have already evolved resistance to triazines and ALS inhibitor herbicides are likely to be among the first to evolve resistance to glyphosate. *Amaranthus* species such as *Amaranthus rudis, Amaranthus retroflexus, Amaranthus hybridus, Amaranthus palmeri,* and *Amaranthus powellii* are widespread and occur at high densities throughout the cropping regions of the United States. They are also highly adaptable and have shown capability to evolve resistance to seven herbicide modes of action. Clearly, *Amaranthus* species are going to be among the most problematic herbicide resistance problems in the Midwest. Given that glyphosate resistance has been identified in *Amaranthus palmeri* in Georgia, it is highly likely that glyphosate-resistant *Amaranthus rudis, retroflexus,* or *hybridus* will soon evolve in the Corn/Soybean Belt. Many of these populations also may be resistant to other herbicide modes of action, such as triazines, ALS inhibitors, and protoporphyrinogen oxidase (PPO) inhibitors. When this happens over a large area, weed control will no longer be quick, easy, and inexpensive. The lack of research and development of new herbicide modes of action will exacerbate the problem. I think that growers will look back on the years between 1996 and 2015 as the good old days, when Roundup Ready crops made weed control simple and inexpensive.

## Acknowledgements

I thank the Herbicide-Resistance Action Committee (HRAC), the North American Herbicide Resistance Action Committee (NAHRAC), and the Weed Science Society of America for funding the International Survey of Herbicide Resistant Weeds, the primary source of data for this paper. Many thanks also are due to all of the research and extension weed scientists that have contributed to the online survey.

## References

Devine, M. D., S. O. Duke, and C. Fedtke. 1993. Physiology of herbicide action. Prentice Hall, Englewood Cliffs, NJ.

Feng, P.C.C., J. E. Pratley, and J. A. Bohn. 1999. Resistance to glyphosate in *Lolium rigidum*. II. Uptake, translocation, and metabolism.. Weed Science 47: 412–415.

Heap, I. and R. Knight, R. 1986. The occurrence of herbicide cross-resistance in a population of annual ryegrass, *Lolium rigidum*, resistant to diclofop-methyl. Australian Journal of Agricultural Research 37: 149–156.

Heap, I. M. and H. LeBaron. 2001. Introduction and overview of resistance, pp. 1–22. *In* S. Powles and D. Shaner [eds.], Herbicide resistance and world grains. CRC Press, Washington, DC.

Heap, I. M. (2005) International survey of herbicide-resistant weeds. U.S.A., WeedSmart, Corvallis, OR. http://www.weedscience.com.

Heck, G. R., S. Y. Chen, T. Chiu, P. Feng, J. Juang, C. S. Hubmeir, Y. Qi, and R. D. Sammons. (2002). Ongoing investigations into glyphosate resistant horseweed: resistance mechanisms studies. North Central Weed Sci. Soc. Abstr. 57: Addendum [CD-ROM Computer File]. North Central Weed Sci. Soc., Champaign, IL. (Dec. 2002).

Holtum, J.A.M., and S. B. Powles. 1991. Annual ryegrass: an abundance of resistance, a plethora of mechanisms. *In* Proceedings of the Brighton Crop Protection Conference, Weeds 3: 1071–1078.

Lee, L. J, and J. Ngim. 2000. A first report of glyphosate-resistant goosegrass (*Eleusine indica* (L.) Gaertn) in Malaysia. Pest Management Science 56: 336–339.

Lorraine-Colwill, D. F., Hawkes, T. R., Williams, P. H., Warner, S.A.J., Sutton, P. B., Powles, S. B., and C. Preston. 1999. Resistance to glyphosate in *Lolium rigidum*. Pestic. Sci. 55: 486–503.

Pratley, J., P. Baines, P. Eberbach, M. Incerti, and J. Broster. 1996. Glyphosate resistance in annual ryegrass. *In* Proceedings of the 11th Annual Conference Grasslands Society NSW, 122.

Pratley J., N. Urwin, R. Stanton, P. Baines, J. Broster, K. Cullis, D. Schafer, J. Bohn, and R. Krueger. 1999. Resistance to glyphosate in *Lolium rigidum*. I. Bioevaluation Weed Science 47: 405–411.

Ryan, G. F. 1970. Resistance of common groundsel to simazine and atrazine. Weed Science 18: 614.

Tran, M. S., S. Baerson, R. Brinker, L. Casagrande, M. Faletti, Y. Feng, M. Nemeth, T. Reynolds, D. Rodriquez, D. Schafer, et al. 1999. Characterization of glyphosate-resistant *Eleusine indica* biotypes from Malaysia. *In* Proceedings of the 1999 Asian-Pacific Weeds Conference Bangkok, Thailand.

VanGessel, M. J. 2001. Glyphosate-resistant horseweed from Delaware. Weed Science 49: 703–705.

# What the $#%@& is Going on with Lambsquarters and Glyphosate?

Mark M. Loux

One of the characteristics of Roundup Ready soybean in the first few years after their introduction was the notable absence of weeds after postemergence glyphosate applications. This situation applied to relatively easy-to-control weeds as well as those that are not well controlled by other herbicides. However, populations of horseweed, common ragweed, and waterhemp have developed resistance to glyphosate over the past 5 years, because of reliance on exclusively glyphosate in soybean. There also has been a tendency for the control of several other weeds, such as common lambsquarters and giant ragweed, to be reduced in Roundup Ready soybean, especially late in the season. The question is, Why has control of these weeds decreased in some fields? Does most of the blame rest with our management of glyphosate and failure to integrate glyphosate with other appropriate herbicides, or are some populations evolving to be less sensitive to glyphosate? We think it's probably a combination.

## These are Tough Weeds

Lambsquarters and giant ragweed can be generally difficult to control, especially where the weed management program relies on postemergence herbicides exclusively. Lambsquarters is effectively controlled by many preemergence soybean herbicides, but it is controlled, variably, by only three postemergence soybean herbicides: thifensulfuron (Harmony GT), imazamox (Raptor), and glyphosate. Lambsquarters is most easily controlled soon after emergence when small, and it seems to become more difficult to control with increasing size and age. Whereas lambsquarters is not really considered to be a late germinator, we have observed lambsquarters plants emerging after postemergence glyphosate applications. These plants can become late-season weed problems unless adequately suppressed by the soybean canopy or treated with herbicides. Lambsquarters populations have developed resistance to triazine herbicides, mostly in continuous corn, and lambsquarters seed can be abundant in the seed bank in these fields due to previous periods of poor control. Resistance to ALS inhibitors has been observed in several lambsquarters populations in the Midwest.

Giant ragweed has a number of characteristics that make it a "great" weed, and inherently difficult to control. It is large-seeded, and emergence can occur from seeds buried several inches deep. In soybean, several ALS-inhibiting preemergence herbicides provide partial control of giant ragweed, but a subsequent postemergence treatment is almost always required. Giant ragweed populations in the eastern Corn Belt can emerge continuously from late March until early July, and populations farther west are evolving to have the same characteristic. It is therefore often difficult to know when to initially apply postemergence herbicides, and there is a tendency among producers to delay application somewhat to control later emerging plants. This delay can result in the presence of large giant ragweed plants at the time of postemergence application, especially because giant ragweed grows roughly twice as fast as other broadleaf weeds. Postemergence herbicides may be less effective in large plants. Late-emerging giant ragweed can require a second postemergence treatment, which producers may be reluctant to apply. Certain ALS inhibitors and glyphosate are the postemergence herbicides most effective on giant ragweed, whereas the effectiveness of diphenylether herbicides occurs primarily on small plants. Many giant ragweed populations in the eastern Corn Belt have developed resistance to ALS inhibitors, which greatly reduces the number of preemergence

and postemergence herbicides that can be used to manage this weed. Giant ragweed plants can become infested with stem-boring insects, which may reduce herbicide effectiveness.

## Management Issues

Some of the problems with ineffective control of lambsquarters and giant ragweed are because of the management of glyphosate, especially rate, timing, and number of applications. It is possible to observe within short distances individual Roundup Ready soybean fields that vary greatly in the effectiveness of the weed control, and this can be attributed to differences in the level of management between fields. The impact of soybean cultural practices and the competitiveness of the soybean crop also must be considered here. Early planting, the slow early-season growth of soybean in no-tillage, and the impact of diseases on soybean stand establishment and crop development can result in the need for an herbicide program that controls weeds for up to 10 weeks after planting.

Controlling weeds for this duration requires the use of a multiple application herbicide program, with integration of several different herbicide application timings and types of herbicides. The essential applications in no-tillage Roundup Ready soybean are 1) either a fall or spring treatment to control winter annual weeds, and in the case of preplant spring treatments, early emerging summer annuals; 2) an early postemergence glyphosate application when weeds are 4 to 8 inches tall; and 3) a second postemergence application as necessary to control late-emerging weeds or those not completely controlled with the first application. Producers who integrate glyphosate with other herbicides, as in the inclusion of residual herbicides in fall or preplant treatments, may improve control of certain weeds and reduce selection for glyphosate resistance. Deviation from this two- to three-application program can result in less effective weed control in general, but problems may be most acute with weeds such as giant ragweed and lambsquarters.

## What is the "Right" Rate?

Current research at Ohio State University and other universities indicates that the "right" rate of glyphosate to achieve consistently effective control of lambsquarters and giant ragweed is probably higher than the rate most typically applied by producers. There is a tendency among producers to use a glyphosate rate of no more than 0.75 lb acid equivalent (a.e.)/acre regardless of the weed species or size. However, research at several universities indicates that consistent control of lambsquarters and giant ragweed is more likely to occur with a glyphosate rate of 1.1 to 1.5 lb a.e./acre. Factors that affect control may include size and age of plants, variation in the sensitivity of populations to glyphosate, environmental conditions, dust on the leaves caused by spray application traffic, and infestation with stem-boring insects. Control of giant ragweed with glyphosate is also influenced by the time of day of application, with control often reduced in the evening through early morning. Use of higher glyphosate rates can help offset possible reductions in control that are the result of many factors but that will not overcome the effect of time of day.

## Are Populations Becoming Less Sensitive to Glyphosate?

The more frequent mid-to-late-season infestations of lambsquarters and giant ragweed in the past several years could be an indication of the evolution of weed populations in response to intensive use of glyphosate. Weed scientists at OSU have conducted greenhouse and field studies with several populations that seem to have reduced sensitivity to glyphosate. In greenhouse studies, plants from several populations of lambsquarters have survived a glyphosate rate of 3.0 lb a.e./acre, as have plants from one population of giant ragweed.

The giant ragweed population was from a field that had been planted with Roundup Ready soybean continuously for a number of years and that was treated with exclusively glyphosate during this period. Giant ragweed in the field was not adequately controlled with two postemergence applications of glyphosate in 2004, and seeds were collected from the field in the latter part of that growing season. In an initial greenhouse study, control of this population 20 days after treatment (DAT) was 64 and 79% at glyphosate rates of 0.75 and 3.0 lb a.e./acre, respectively, compared with 78 and 94% control of a sensitive population. Based upon these results, two field studies were conducted in Roundup Ready soybean in 2005. In a large-plot study, glyphosate applied postemergence at 0.75 and 1.5 lb a.e./acre controlled 70 and 80% of the giant ragweed 23 DAT, respectively, and control increased to 90 and 94% by 21 DAT after a second postemergence glyphosate application. Control had further improved by the time of soybean harvest, although some plants survived and produced seed, primarily in the plot treated with 0.75 lb a.e./acre initially.

In a small-plot study, glyphosate controlled from 56 to 79% of the giant ragweed 23 DAT when applied postemergence at rates ranging from of 0.75 to 3.0 lb a.e./acre, respectively. At 21 days after a second pos-

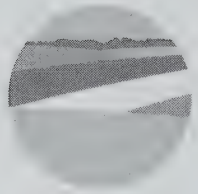
temergence application of 1.5 lb a.e./acre glyphosate, control ranged from 84 to 94% for this series of treatments. At the time of soybean harvest, we were able to find surviving plants with seed primarily in the plots treated with 0.75 lb and 1.1 lb a.e./acre initially, but we also found a few plants with seed where higher rates were applied. These plants seem to have developed reduced sensitivity, or possibly resistance, to glyphosate due to the intensive and exclusive use of this herbicide for giant ragweed control over a number of years. Although ALS-resistant ragweed populations are common in Ohio, we have not yet characterized this population for its response to ALS inhibitors in the greenhouse.

Preliminary greenhouse research identified six lambsquarters populations with a reduced response to glyphosate. This research has tended to be characterized by some variability in response among replications within experiments, and also among experiments. However, dose-response studies indicate that several populations may be 3 to 4 times less sensitive to glyphosate than susceptible populations. Large-plot field studies were conducted at six sites, in a manner similar to the giant ragweed field studies. At approximately 21 DAT, control ranged from 85 to 99% for a glyphosate rate of 0.75 lb a.e./acre, and from 94 to 99% for a rate of 1.5 lb. A second glyphosate application, in plots receiving 0.75 lb a.e./acre initially, improved control to 95 to 99%. At most sites, lambsquarters was more effectively controlled within the plots that were treated with glyphosate twice, compared with the rest of the field that was treated with glyphosate only once. At five of the six sites, we observed plants surviving two applications of glyphosate, although they were few, small, and may have germinated after the initial application. We also observed small patches of surviving plants at several sites, which could be indicative of past seed production from one or more plants with reduced sensitivity to glyphosate. Plants surviving two glyphosate applications, although small, produced seed that seemed to be viable. Additional greenhouse studies will be conducted with this seed to further characterize plants that survived multiple glyphosate applications in the field.

## Guidelines for Management of Lambsquarters and Giant Ragweed

The following guidelines can help maintain effective control of lambsquarters and giant ragweed in Roundup Ready soybean, and slow the rate of development of reduced sensitivity to glyphosate that may be occurring.

1. Rotate crops and avoid herbicide programs that rely on the repeated use of one herbicide site of action within and over years. Avoid reliance on herbicide programs that consist exclusively of postemergence herbicides. Use a combination of preemergence and postemergence herbicides in soybean and corn.
2. Ensure that the field is free of lambsquarters and giant ragweed at the time of planting, through use of tillage or preplant burndown herbicide treatments where 2,4-D ester is applied with glyphosate or paraquat.
3. Apply preemergence herbicides with significant activity on lambsquarters and giant ragweed, to reduce the dependence upon the postemergence glyphosate application. Most preemergence soybean herbicides with broadleaf activity effectively control lambsquarters well into the growing season. Several preemergence, ALS-inhibiting herbicides, Synchrony XP, Scepter, FirstRate, and Gangster, can control giant ragweed into the early part of the growing season, or at least reduce the number of plants present at the time of postemergence application. However, a number of ragweed populations in the Midwest have developed resistance to ALS inhibitors, and these preemergence herbicides will be more ineffective in these populations.
4. Make the initial postemergence glyphosate application when lambsquarters and giant ragweed plants are less than 6 inches tall and follow with an additional application as needed to control later emerging plants or plants that survived the first treatment. Fields should be scouted closely for plants within the soybean canopy that were not completely controlled by an initial glyphosate treatment. These plants may appear greatly injured and stunted, but they can often regrow and reach heights above the soybean canopy later in the season. A second postemergence application approximately 3 weeks after the first can complete the control of many of these plants. Those plants that are still not killed will have greatly reduced seed production.
5. Use a glyphosate rate of 1.1 to 1.5 lb a.e./acre for initial postemergence applications on lambsquarters and giant ragweed, and use 1.5 lb a.e./acre for plants more than 6 inches tall. Use a rate of 0.75 lb a.e./acre in subsequent postemergence applications. Glyphosate labels allow a total of 2.25 lb a.e./acre for all postemergence applications. Avoid application of rates higher than 0.75 lb a.e./acre glyphosate late in the season, because of the potential for minor injury to soybean.



# A Business Perspective on Weed Resistance

Larry Weller

Herbicide-resistant weeds are not new to us. Looking back through time, we can find a number of weeds (that we have selected out through our production practices) that we could not control with our favorite products. Some examples include the triazine-resistant smooth pigweed and common lambsquarters. Scepter was the tool for cocklebur, until we selected resistant biotypes. Pursuit was king of the hill, until ALS-resistant waterhemp gained a foothold. The solution each time has been change, particularly a change to a more effective herbicide or approach that does not have the hole, and move on. The development of ALS-resistant waterhemp was a major factor for the adoption of Roundup Ready soybean and helped lead to their dominance in the soybean marketplace. Roundup plugged the hole and brought some other nice advantages along with it.

Any new development of a weed with resistance is initially *bad news*! I have a grouping of words that somewhat reflect the process: surprise, amazement, disappointment, frustration, time drain, and economic loss. However, new weed resistance also triggers a learning process of how to deal with it and where to turn next. So, we have reflection and review, information gathering and exchange. Based on new knowledge, we make changes in our control efforts. Like many other cases, problems create new opportunities as we work to solve them.

We are in the seed business, and it is a significant component of our activities. The increase in Roundup Ready technology has pushed the issue of weed resistance to glyphosate. Glyphosate-resistant corn will be a big player. It offers many of the same benefits in corn that we have experienced in soybean. Most of us have the desire to bring new technology to the marketplace. At the same time, we are having some large misgivings about the likelihood of having to deal with an increasing number of weeds that will not be controlled by glyphosate. A devalued marketplace for crop protection products does not provide the payback "value added practitioners" need. They may be unable or unwilling to spend the time needed to develop recommendations for programs or practices that decrease the selection pressure for resistant weeds. It will be important for seed salesmen to assist in development of best management practices to reduce the potential for glyphosate-resistant weeds. Solutions for potential future glyphosate-resistant weed problems are not readily evident from a pipeline of new products. So, we are caught in sort of a catch-22 situation.

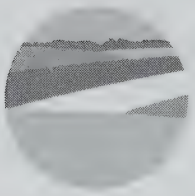
The weed science community, particularly extension, has been very active at sounding the alarm regarding glyphosate-resistant weeds by raising awareness, trying to educate growers, and pointing out alternative pathways for consideration to aid in reducing potential impacts of resistance. Internal survey work we recently completed with GROWMARK crop sales specialists yielded some interesting results. We feel we have a fairly high level of understanding of what to do to reduce selection pressure. The problem we face is that the best choices have a higher price tag and will take sales efforts to get them implemented.

We have been surprised by the variety of positions manufacturers have taken in dealing with glyphosate resistance. One would assume they would all say "Let's do all we can to delay the development of glyphosate-resistant weeds." Instead, a range of positions is realized: It can't happen, It won't happen, It could happen, It will happen, It's going to happen, It has happened.

These variations are reflected in their specific product positioning and supporting marketing programs. It does seem, however, that there is more concern today than we have seen in previous years.

And so, where to from here? We have a range of grower awareness levels to the potential problems we face with glyphosate-resistant weeds. We need to continue our efforts to raise awareness and to inform. And we face a range of grower responses as to what practices they will implement. We need to continue to offer to growers ideas for alternative strategies that reduce selection pressure. This approach should be a seed-positioning activity for us as well as a weed management planning activity. We need to continue to deliver feedback to manufacturers regarding their product positioning and marketing programs, so they move in a useful direction.

We play the hand we are dealt to the best of our ability, and we adjust as the need arises. When faced with the reality of a population of glyphosate-resistant weeds, we will need to be ready to help implement the necessary product or program changes, as we see them currently.



# The Illinois Outlook: Can It Happen Here?

Aaron Hager

Since the commercialization of glyphosate-resistant crops, the question of whether glyphosate-resistant weeds will or will not be selected has been extensively bantered around by individuals involved in virtually all phases of production agriculture. Those in academia have (generally) agreed on at least two points: 1) the potential for selecting weed biotypes resistant to glyphosate is less than that associated with selecting biotypes resistant to other herbicide families, and 2) never say it will never happen. Many agrichemical retailers initially expressed high degrees of satisfaction with the level of weed control provided by glyphosate, but some are currently very concerned with what may be described as a "reduced consistency" of performance. Some manufacturers of glyphosate initially expressed confidence that glyphosate-resistant weeds would not become an issue with which farmers or agrichemical retailers would have to contend, whereas other manufacturers voiced near-apocalyptic concerns about the likely consequences of over-reliance on a single active ingredient. Whichever position you might have taken on this question during the early years of glyphosate use in-crop, the facts are as follows: glyphosate-resistant weed populations have been selected; these resistant populations represent more than one weed species; several states, from the Midwest to the east coast, have reported instances of glyphosate-resistant weeds; and we have no evidence to suggest that Illinois will be "immune" to this phenomenon.

An important step in avoiding the problems caused by herbicide-resistant weeds is to understand how a resistant weed population develops. Evidence suggests that herbicide-resistant weeds are naturally occurring biotypes that initially exist in very low numbers within the population of a particular weed species. Plants that possess certain traits or characteristics not common to the entire species are referred to as biotypes. When a particular herbicide effectively controls the majority of susceptible members of a species, only those plants that possess a resistance trait can survive and produce seed for future generations. This is often referred to as the natural selection theory or survival of the fittest. Biological organisms (e.g., people, plants, animals) are diverse. The plants in a population that possess characteristics enabling them to survive under a wide range of environmental and other adverse conditions (such as herbicide applications) will be able to produce seed that maintains these survival characteristics. Plants less adapted generally do not survive, and hence only the fittest plants reproduce.

What, then, is meant by the phrase "selection pressure" with respect to herbicide-resistant weeds? Most herbicides are used to control a broad spectrum of weeds. By controlling susceptible members of a weed population, we are essentially using herbicides as agents to select for biotypes that are naturally resistant to the herbicide. These resistant biotypes are better adapted to survive in the environment created by controlling susceptible members of the population. The seed produced by the resistant biotypes ensures that the resistance trait will carry on to future generations. If the same or a similar herbicide is used repeatedly (year after year or several times during the growing season), the resistant biotypes continue to thrive, eventually outnumbering the normal (susceptible) population. In other words, relying on the same herbicide for weed control creates a selection pressure that favors the development of herbicide-resistant weeds.

The development of herbicide-resistant weed populations may thus be summarized by the following sentence: *The appearance of herbicide-resistant weeds is the consequence of repeatedly using the same or similar herbicide (usually a herbicide with a single site of action) to control a specific weed species not controlled by any other herbicide or in any other manner.* The process of selection for herbicide-resistant biotypes begins the first time a particular herbicide active ingredient is applied to any given field.

In April 2005, we reported on three horseweed (*Conyza canadensis*) populations from Illinois that were not controlled with glyphosate in greenhouse experiments. The populations we have examined originated from three counties in Illinois: Douglas, McLean, and Schuyler. Only one of these populations was sent to us by a concerned farmer who noted poor control of horseweed after a burndown application of glyphosate in 2004. The other two populations were collected during weed survey and collection campaigns in 2004. The geographic dispersion of these populations suggests there may not be a "concentrated" area of concern in the state, but rather farmers and applicators across Illinois should remain vigilant. Glyphosate-resistant horseweed was first identified in Delaware in 2000. Since the initial discovery in Delaware, glyphosate-resistant horseweed populations have been identified in 10 other states, including our neighboring states of Indiana and Missouri. Weed scientists in the 11 states where these populations are known to exist have conducted extensive field, greenhouse, and laboratory experiments to further our understanding of the mechanism these plants use to survive glyphosate as well as how best to manage these resistant populations under field conditions.

To date, horseweed has been the only weed species we have identified from Illinois fields with suspected resistance to glyphosate. Arguably, farmers have many viable alternative herbicides for control of glyphosate-resistant horseweed (at least before soybean planting). But, will there be viable alternatives for control of other glyphosate-resistant species? What if glyphosate resistance became predominant in summer annual weed species? If glyphosate-resistant species are not common in Illinois at this time, should Illinois farmers be concerned? Are there "new" instances of glyphosate resistance with which Illinois farmers should be aware?

At least one biotype of Palmer amaranth (*Amaranthus palmeri*) in Georgia demonstrates resistance to glyphosate. This population was identified growing in a field of glyphosate-resistant cotton, and weed scientists at the University of Georgia estimate this biotype currently infests approximately 500 acres. Palmer amaranth is a summer annual species of pigweed. It is an aggressive species that can reach heights of 4 to 7 feet and produce large amounts of seed. Research has demonstrated that among the pigweed species common to the Midwest, Palmer amaranth has the fastest growth rate and is the most competitive with row crops. You might think of Palmer amaranth as waterhemp's big bad brother! The occurrence of glyphosate-resistant Palmer amaranth in Georgia (and suspected cases in Tennessee and North Carolina) should raise awareness among Illinois farmers because 1) this example illustrates resistance to glyphosate can occur in a summer annual weed species that is very competitive with corn and soybean and 2) Palmer amaranth is indigenous to Illinois. If glyphosate-resistant Palmer amaranth can occur in other states, it seems likely that it can occur in Illinois.

Perhaps the example of glyphosate-resistant Palmer amaranth may not elicit a great deal of concern or provide sufficient evidence to justify a significant change in weed management practices in Illinois because this species is not tremendously widespread in Illinois. Horseweed resistant to glyphosate may cause some level of concern, but that particular species is generally more of a problem before planting than after crop emergence, and preplant tillage remains as an effective management option. What if some other summer annual weed species with resistance to glyphosate were to be discovered? Would glyphosate-resistant waterhemp be more of a concern? Is it at all possible that glyphosate-resistant waterhemp could become a problem for Illinois farmers? Farmers in our neighbor state of Missouri may be faced with this scenario before Illinois farmers are faced with it. Researchers at the University of Missouri have reported two populations of waterhemp that have consistently survived after glyphosate applications under field and greenhouse conditions. News releases from Missouri reported some of these waterhemp plants survived up to 6 lb a.e. glyphosate (a rate approximately equivalent to 170 fluid ounces of Roundup Original Max). If glyphosate-resistant waterhemp can occur in other states, it seems likely that it can occur in Illinois.

Will these "new" cases of glyphosate-resistant weeds be sufficient to persuade changes to weed management programs in Illinois, especially Illinois soybean produc-

**Table 1. Chronology of glyphosate-resistant weeds around the world**

| Common name | Scientific name | Location and year identified |
|---|---|---|
| Rigid ryegrass | *Lolium rigidum* | Australia (Victoria) 1996<br>Australia (New South Wales) 1997<br>California 1998<br>Australia (South Australia) 2000<br>South Africa 2001 |
| Goosegrass | *Eleusine indica* | Malaysia 1997 |
| Horseweed | *Conyza canadensis* | Delaware 2000<br>Kentucky, TN 2001<br>Indiana, Maryland, New Jersey, Ohio 2002<br>Arkansas, Mississippi, North Carolina, Ohio, Pennsylvania 2003<br>California 2005 |
| Italian ryegrass | *Lolium multiflorum* | Chile 2001<br>Brazil 2003<br>Oregon 2004 |
| Buckhorn plantain | *Plantago lanceolata* | South Africa 2003 |
| Hairy fleabane | *Conyza bonariensis* | South Africa 2003<br>Spain 2004 |
| Common ragweed | *Ambrosia artemisiifolia* | Missouri 2004 |
| Palmer amaranth | *Amaranthus palmeri* | Georgia 2005 |

tion? Only time will provide an accurate answer to that question. However, we continue to stress several points related to glyphosate-resistant weeds and glyphosate stewardship:

1) A selection pressure for herbicide-resistant weeds occurs each time the same herbicide is applied to a particular field.

2) Increased adoption of glyphosate-resistant corn hybrids, with a concomitant use of glyphosate to the exclusion of other weed management tools, will speed the selection of glyphosate-resistant weeds.

3) Rotating herbicides (sites of action) or tankmixing herbicides will help slow the selection of glyphosate-resistant weeds, but it is unlikely to completely prevent their selection. Keep in mind that it's near impossible to make "blanket statements" about how effective a particular alternative herbicide or tankmix partner will be in slowing the selection of glyphosate-resistant weeds.

4) Stewardship of glyphosate herbicide is an easy concept to discuss but more difficult to implement. Manufacturers often have differing messages about stewardship, but it may be wise to ask yourself why a particular manufacturer seems to be concerned with stewardship of glyphosate.

In summary, the preponderance of evidence suggests it is only a matter of time until glyphosate-resistant weeds begin to occupy places in the Illinois agronomic landscape. Farmers and retailers alike will likely experience adverse financial consequences as a result of continued heavy reliance on a single herbicide active ingredient.

# Western Bean Cutworms Expand Their Range in 2005: Expectations for 2006

KELLY A. COOK

The western bean cutworm (Lepidoptera: Noctuidae) was first discovered in Illinois in 2004. It has historically been a pest in the western Corn Belt. Over the past several years, it has become established in western Iowa, steadily moving eastward. In 2004, the western bean cutworm was discovered in southeastern Iowa as well as Warren County, Illinois, and Harrison and Putnam counties in Missouri.

## Life Cycle of Western Bean Cutworm

Generally, only one generation of western bean cutworm occurs each year, with adult moth emergence beginning in late June or early July. Adult flight peaks in mid-July and ends in mid-August. In corn, female western bean cutworms lay eggs primarily on the upper leaf surfaces. Fields attractive to western bean cutworms for oviposition are those in which corn is tasseling or near tasseling and fields that have hybrids with upright leaf characteristics. Larvae hatch within 5 to 7 days after the eggs are laid.

The larvae pass through five instars and feed on host plants for ffi1 mo. First instars are very mobile and may infest several host plants. As larvae develop, their color changes from dark brown (first instar) to light tan, with brown hatch markings on their backs becoming more distinct with age. When larvae develop to the third instar, they have three dark stripes just behind the head. This characteristic helps differentiate the western bean cutworm from other caterpillars feeding in cornfields. After a larva finishes feeding and completes development, it drops to the ground and burrows beneath the soil, where it constructs an overwintering cell. Western bean cutworms spend the winter in the prepupal stage. In May, western bean cutworms pupate, and emerge as adults in midsummer.

## Western Bean Cutworm Injury

Unlike other cutworms, the western bean cutworm is a late-season pest of corn. Newly hatched larvae move to the corn whorls where they feed on the flag leaf, tassel, and other yellow tissue. As pollination begins, larvae move to and begin feeding on developing silks. However, the western bean cutworm feeds primarily on corn ears. As both larvae and corn ears develop, larvae begin feeding on ear tips. Larvae chew through ear husks to developing kernels, predisposing the ear to fungal and mold infections. Because of their tendency to disperse, larvae from one egg mass may infest other corn plants in the same and adjacent rows in an area 6 to 10 ft in diameter. An infestation of more than one larva per ear may occur because western bean cutworm larvae are not cannibalistic, as are corn earworm larvae.

## 2005 Pheromone Trapping Network in Illinois

The discovery of western bean cutworm adults in Illinois in 2004 prompted the establishment of a network of pheromone traps across Illinois in 2005. This network was established as a cooperative effort between the University of Illinois Extension and Pioneer Hi-Bred International. The goal of this program was to monitor for the presence and distribution of the western bean cutworm in Illinois. Traps were placed in 56 counties throughout northern and much of central Illinois and in some selected counties in southern Illinois. Operation of traps began on 1 July and continued through

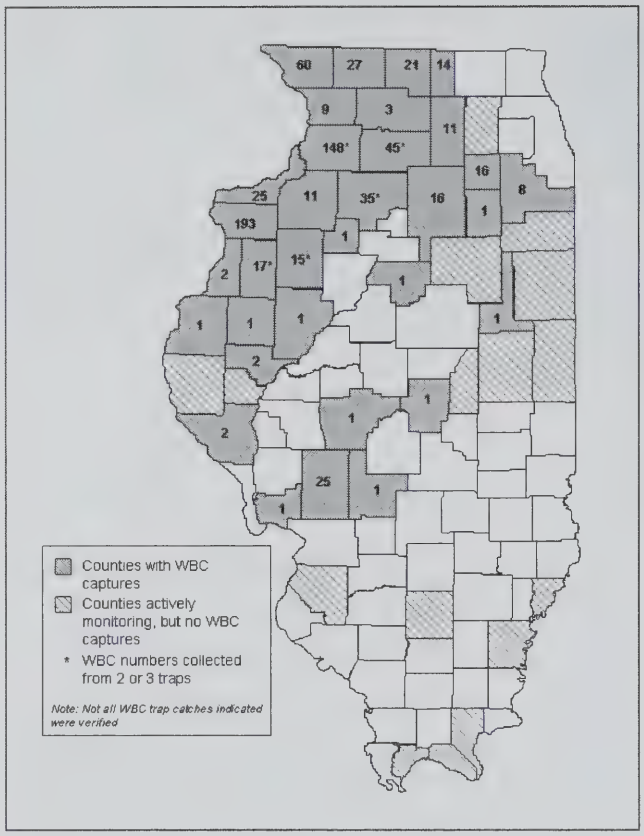



**Figure 1. Reported western bean cutworm moth captures from 2005 western bean cutworm trapping effort.**

15 August. The traps were checked two to three times each week.

At least one moth was caught in 33 of the counties included in the trap network (Figure 1). Trap catches were greater in counties in northwestern Illinois, especially those along the Iowa border. Mercer and Whiteside counties reported the greatest trap catch totals of 193 and 100, respectively. However, trap catches in Illinois pale in comparison with the number of moths caught in western and central Iowa. For example, in western Iowa, counties such as Woodbury, Pocahontas, and Guthrie all reported more than 1,000 western bean cutworm moths in traps placed in their respective counties.

## What Does This Mean for Illinois Corn Producers?

Confirmation of western bean cutworm moths in some Illinois counties indicates that producers will need to monitor for adult moths in the upcoming growing season. Pheromone traps should be used to monitor for moths; and upon their capture, fields should be scouted for larvae and potential injury. Moth emergence also can be predicted by calculating growing degree-days, beginning 1 May, by using a base temperature of 50° F (Table 1).

In corn, check 20 consecutive plants in at least five random locations in each field. Fields planted with different hybrids that vary in maturity and leaf architecture should be scouted extensively and care should be taken to evaluate each hybrid separately. Look for egg masses or small larvae on the upper surfaces of corn leaves. Also, examine tassels for larvae before pollen shed. Entomologists at the University of Nebraska recommend that an insecticide treatment should be considered when 8% of the plants have egg masses, small larvae, or a combination. Timing of an insecticide application is critical. If larvae have hatched, apply an insecticide when 90–95% of the tassels have emerged, but before larvae enter the silks. Control is more difficult after larvae have moved to the silks. If larvae have not hatched and the corn plants have tasseled, time the insecticide application to coincide with the hatch of larvae. Eggs turn from white to tan to dark purple as they age. If the eggs are purple, hatch usually occurs in about 24 h.

## Expectations for 2006

What 2006 and the future holds for the western bean cutworm in Illinois is anyone's guess. We know that before 2000, the western bean cutworm was an occasional pest of corn in Iowa and injury caused by this insect exceeding economic thresholds had never been reported. In 2000, an economically damaging population was found in corn in western Iowa. By 2004, the western bean cutworm was predicted to occur in every Iowa county, although it is considered an economic pest in western and central Iowa.

**Table 1. Degree-day accumulations in relation to percentage of moth emergence (begin 1 May, base 50°F)**

| Accumulated degree-days | % Moth emergence |
|---|---|
| 1319 | 25% |
| 1422 | 50% |
| 1536 | 75% |

These initial findings of the western bean cutworm trap network only signify that the insect is present in Illinois. How its distribution will change over the next few years is uncertain. The pheromone trap network will continue to operate. In 2006, traps will be placed in more counties and additional traps will be placed in counties likely to have increased densities of western bean cutworm. Surveys of cornfields will need to be done to positively identify larvae feeding in fields and to determine the extent of ear damage caused by the western bean cutworm. Diligent monitoring and scouting in 2006 and upcoming years will be required to gain a better understanding of where the western bean cutworm is present and how it will affect corn production in Illinois.

## References


Cook, K.A. (2005) Western bean cutworm factsheet. University of Illinois (http://www.ipm.uiuc.edu/vegetables/insects/western_bean_cutworm/).

Peaurs, F.B. (2002) Western bean cutworm: characteristics and management in corn and dry beans. No. 5.538, Colorado State University, Ft. Collins, CO (http://www.ext.colostate.edu/pubs/insect/05538.pdf).

Rice, M.E., and D. Dorhout (2005) Eastern movement of the western bean cutworm in midwestern field corn. pp. 102-105. In Proceedings of the Illinois Crop Protection Technology Conference. Ill. Coop. Ext. Serv., Urbana-Champaign.

Wright, B., and R. Seymour (1996) Western bean cutworm management: biology, scouting, and control of the western bean cutworm. University of Nebraska, Lincoln (http://entomology.unl.edu.pmguides/wbcutwrm.htm).

# Impact of YieldGard Rootworm on Corn Rootworm Control: A Proven Technology for Producers

Ty T. Vaughn

Corn rootworm (CRW) is the most destructive insect pest of corn in the United States. When last assessed in 1995, CRW was responsible for the largest expenditure by growers for insect management in corn production systems (Pike et al. 1995). It is estimated that CRW has infested 13 million hectares of the 28.5 million hectares of harvested corn in the United States (James 2003). CRW larvae inflict damage to corn plants by feeding on the root tissues, which reduces the ability of the plant to take up water and nutrients from the soil (Reidell 1990). Damaged plants are also prone to lodging, resulting in reduced yield (Spike and Tollefson 1991) and adding significant time to harvesting operations. In addition to the financial costs associated with yield loss, chemical control tactics for CRW also have significant environmental costs. Organophosphate, pyrethroid, carbamate, nicitinoid, and phenyl pyrazole insecticides are typically used to manage this pest. In the United States, more than 80% of all insecticide use is targeted for controlling CRW. Furthermore, certain CRW species have recently overcome crop rotation control strategies through behavioral adaptations. Thus, a pressing need exists for new and effective options for growers to manage CRW.

The advent of biotechnology has provided new tools for controlling insect pests. Transgenic plants have been designed that express insecticidal proteins from the bacterium *Bacillus thuringiensis* (Bt). Bt strains are indigenous to many environments, including soil, and are classified in part by their insecticidal specificity (Schnepf et al. 1998). Bt proteins have been identified that cause mortality to a number of insect species in the orders Lepidoptera (butterflies and moths), Diptera (flies and mosquitoes), Coleoptera (beetles and weevils), and Hymenoptera (wasps and bees). When susceptible insects consume a plant containing the Bt protein, the protein is broken down into shorter proteins that bind to the insect midgut lining. The process of binding causes a pore to form, resulting in damage to the cell membrane to the point where the insect stops feeding and eventually dies.

## Protein Expression and Performance

In 2003, the Monsanto Company commercialized YieldGard® Rootworm (YGRW) protected corn hybrids (Vaughn et al 2005). These hybrids use a variant Bt Cry3Bb1 insecticidal protein (Donovan et al. 1992), which is known to be biologically active against several species within the coleopteran family Chrysomelidae, including western corn rootworm, *Diabrotica virgifera virgifera* LeConte; northern corn rootworm, *Diabrotica barberi* Smith & Lawrence; and Mexican corn rootworm, *Diabrotica v. zeae* Krysan & Smith (Rupar et al. 1991). YGRW expresses the Cry3Bb1 protein in the root system where larvae feed and inflict damage. Thus, the level of expression is critical to the control of the insects that come into contact with the root system. Through a series of experiments, it was shown that although the level of Cry3Bb1 protein may vary between hybrids and over time, the level of protection is not affected by such variation; that is, the expression level in commercial hybrids is sufficient to provide consistent protection for CRW larval feeding (Vaughn et al. 2005).

There are many benefits for growers, consumers, and the environment associated with the commercialization of YGRW. YGRW hybrids are more efficacious than soil- and seed-applied insecticides in protecting

roots from larval feeding damage. The Cry3Bb1 protein produced in the root does not require activation (as do many conventional insecticides), and its performance is unlikely to be impacted by severe environmental conditions. Varieties containing the Cry3Bb1 protein are also combined through conventional breeding with other genetically enhanced corn varieties. Combinations with herbicide tolerance and lepidopteran insect protection provide hybrids to growers that offer more complete crop protection from the most economically damaging insect and weed pests.

This performance and grower satisfaction has been demonstrated over the past 2 yr of commercial experience. YGRW technology was initially launched in 2003 on approximately 400,000 acres. The number of acres has steadily increased over the past 2 yr to approximately 4.5 to 5 million acres in 2005. Growers that have adopted YGRW technology have been extremely pleased with the performance and yield protection generated from planting these hybrids. In 2005, for example, most growers realized a significant yield advantage over other control options. This advantage was likely augmented due to the severe drought in 2005 across much of the Corn Belt. The YGRW technology protected the roots from larval feeding allowing the roots to access water from a deeper zone within the soil profile.

## Insect Resistance Management

Insect resistance management (IRM) is an import component of the overall stewardship of Bt crops. One of the strategies currently being implanted relies on monitoring of populations for changes in the susceptibility of the protein. Documenting the variation in susceptibility to Bt toxins among geographically distinct populations has become a common theme in establishing sustainable resistance management programs. The initial steps in implementing such programs include development of appropriate bioassay techniques and establishment of baseline susceptibility data among populations across the geographic range of the target species. With this information, potential population susceptibility changes in response to selection with Bt can be identified (Fischhoff 1996) and mitigated. Several years of baseline data and subsequent monitoring have been completed and the results indicate low levels of variation in the populations surveyed, and no changes in susceptibility to date.

## References


Donovan, W.P., M.J. Rupar, A.C. Slaney, T. Malvar, M.C. Gawron-Burke, and T.B Johnson. 1992. Characterization of two genes encoding *Bacillus thuringiensis* insecticidal crystal proteins toxic to Coleoptera species. Applied and Environmental Microbiology 58: 3921–3927.

Fischhoff, D.A. 1996. Insect-resistant crop plants, pp. 214-227. *In* G.J. Persley [ed.], Biotechnology and integrated pest management. CAB International, Wallingford, United Kingdom.

James, C. (2003). Global review of commercialized transgenic crops: 2001. Feature: Bt maize. (ISAAA brief 29). International Service for the Acquisition of Agri-biotech Applications, Ithaca, NY.

Pike, D. 1995. Biologic and economic assessment of pesticide use on corn and soybeans. Report 1-CA-95. USDA-National Agricultural Pesticide Impact Assessment Program, Washington, DC.

Reidell, W.E. 1990. Rootworm and mechanical damage effects on root morphology and water relations in maize. Crop Sciuence 30, 628–631.

Rupar, M.J., W.P. Donovan, R.G. Groat, A.C. Slaney, J.W. Mattison, T.B. Johnson, J.F. Charles, V.C. Dumanior, and H. DeBarjac. 1991. Two novel strains of *Bacillus thuringiensis* toxic to coleopterans. Applied and Environmental Microbiology 57: 3337–3344.

Schnepf, E., N. Crickmore, J. Van Rie, D. Lereclus, J. Baum, J. Feitelson, D.R. Zeigler, and D.H. Dean. (1998) *Bacillus thuringiensis* and its pesticidal crystal proteins. Microbiology and Molecular Biology Reviews 62: 775–806.

Spike, B.P., and J.J. Tollefson. 1991. Yield response of corn subjected to western corn rootworm (Coleoptera: Chrysomelidae) infestation and lodging. Journal of Economic Entomology 84: 1585–1590.

Vaughn, T.T. T. Cavato, G. Brar, T. Coombe, T. DeGooyer, S. Ford, M. Groth, A. Howe, S. Johnson, K. Kolacz, C. Pilcher, J. Purcell, C. Romano, L. English, and J. Pershing (2005). A method of controlling corn rootworm feeding using *Bacillus thuringiensis* protein expressed in transgenic maize. Crop Science 45: 931–938.

# Transgenic Corn Rootworm Hybrids, Soil Insecticides, and Seed Treatments: Does Anything Work on the Variant Western Corn Rootworm?

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Jared B. Schroeder, and Darren M. Bakken

Summer 2005 will long be remembered as one of Illinois' hottest and driest. By 30 September, the number of days that equaled or exceeded 90°F was impressive for many locations: Chicago (Midway), 35 d (departure from average = +13.9 d); Chicago, O'Hare, 26 days (+8.2); Rockford, 31 d (+16.8); Moline, 42 d (+18.5); Peoria, 51 d (+29.7); Springfield, 50 d (+21.2); Quincy, 48 d (+23.5); Champaign-Urbana, 44 d (+23.3); and Carbondale, 63 d (+27.0). These and other data can be retrieved from the Illinois State Climatologist Web site at http://www.sws.uiuc.edu/atmos/statecli/Dry2005/Hot2005.htm. Jim Angel, state climatologist, reported in FarmWeek (August 15, 2005) that the period from 1 March through July was the sixth driest (statewide) since 1895 (8 in. below normal). Unlike the 1988 drought, which was much broader in scope gripping the U.S. North Central region, this year's drought was much more localized with Illinois as the prime target. Under these extreme weather conditions, the impact of root pruning and silk clipping inflicted by western and northern corn rootworms intensified.

Research conducted over several growing seasons in DeKalb and Urbana during the mid-1990s indicated that corn hybrids differed considerably in their ability to regenerate root tissue after pruning by corn rootworm larvae (Gray and Steffey 1998a). Dry soil conditions further reduced the ability of some hybrids to compensate for corn rootworm larval injury. In 2005, densities of western and northern corn rootworms reached very significant levels—a recurring theme from several of the most recent growing seasons. In addition, the variant western corn rootworm expanded its range in Illinois as verified by on-farm "digs" in rotated cornfields in western and southern counties (http://www.ipm.uiuc.edu/bulletin/article.php?id=416). As of 2005, the variant western corn rootworm has established throughout central and northern Illinois. Although densities are lower in extreme northwestern and western counties, variant western corn rootworm adults can now be observed commonly in soybean fields in those regions of the state. We anticipate densities of the variant western corn rootworm to continue their increase in southern counties of Illinois during the next several years. This range expansion of the variant western corn rootworm is unfortunate because of the added insect management costs that corn producers will incur at a time when projected overall production costs are expected to increase. Variable costs for Illinois' grain farmers are projected to be $55 per acre greater for corn during 2006 compared with 2002 (Gary Schnitkey, http://www.farmdoc.uiuc.edu/manage/newsletters/fefo05_18/fefo05_18.html). With these escalating production costs, producers will need to make very informed management decisions for insects in corn and soybean during the 2006 growing season. These decisions are particularly important for western corn rootworms because of their potential destructiveness as larvae and adults.

In this article, we report on the effectiveness of insecticidal seed treatments, soil insecticides, and transgenic corn rootworm hybrids (MON 863) that were evaluated (2005) in our experimental trials located near DeKalb, Monmouth, and Urbana. All of our corn rootworm product efficacy experiments are planted directly on plots that were planted to a trap crop the preceding season. Our trap crops consist of late-planted corn that is interplanted with pumpkins. By using trap crops, we ensure that products are tested under rigorous condi-

tions. Although it is less common to witness root injury as intense as occurred in our experiments, we have observed (including this season) severe root damage and lodging in producers' fields through the years. We believe the results from our trials better enable producers to make the most informed choices regarding product selection for corn rootworms.

## Corn Rootworm Product Efficacy Results

Root injury (0 to 3 scale) in our checks at DeKalb, Monmouth, and Urbana (Table 1) was severe and nearly identical, 2.37, 2.25, and 2.32, respectively (Oleson et al. 2005). These root rating averages indicate that 2⅓ of nodes were destroyed on plants within our check treatment at each site. All treatments were four rows wide by 45 ft in length and were replicated four times (Monmouth—three replicates were used). Root rating averages were obtained by rating five roots for each replicate by treatment combination (20 roots per treatment). A preliminary review of these root rating data from DeKalb, Monmouth, and Urbana indicates the following:

- The granular soil insecticides performed very well under intense corn rootworm larval pressure. At each location, root injury was almost always below a rating of 0.5 (half-node of roots pruned). Differences in root protection among the soil insecticides were generally insignificant.
- Root rating averages (each location) in the Poncho 250 and 1250 plus Aztec 2.1G treatments were not statistically different from each other or the Aztec 2.1G or Aztec 4.67G treatments.
- Root rating averages in the Capture 2EC (DeKalb, 1.44; Monmouth, 0.99; and Urbana, 1.46) and Regent 4SC treatments (1.64, 1.53, and 2.25) were not satisfactory. Although Lorsban 4E performed better in DeKalb (0.49, ½ node destroyed) and Monmouth (0.26, ¼ node destroyed), nearly a full node (0.91) of roots with this treatment was pruned in Urbana. The Lorsban 75WG treatment had root injury that nearly equaled 1½ nodes of roots pruned in both DeKalb and Urbana. In Monmouth, approximately ½ node of roots was pruned in this treatment.
- The Poncho 1250 treatment provided statistically better root protection than the check in each of the experiments. Root pruning in the Poncho 1250 treatment at DeKalb was slightly less than 1 node of roots pruned (0.78), whereas in Urbana, slightly more than 1 node of roots were pruned (1.21). In Monmouth, approximately ½ node (0.55) of roots was pruned in the Poncho 1250 treatment.
- The YieldGard Rootworm (MON 863) treatment in Monmouth (0.04) and Urbana (0.19) provided excellent root protection through 25 and 13 July, respectively. In DeKalb, more root pruning (as of 26 July), particularly on brace roots, was observed in the YieldGard Rootworm treatment with nearly ¾ of a node (0.7) destroyed.

Overall, these results are somewhat similar to what we have observed in previous years for a number of the treatments. Despite the very hot temperatures and somewhat dry soil conditions (especially DeKalb and Monmouth through the first-half of the summer; Table 2), the granular products provided very good to excellent root protection. However, these corn rootworm products will continue to be challenged more intensively as planting dates are pushed back earlier and earlier in the spring. The importance of proper calibration and incorporation cannot be overemphasized for the granular soil insecticides. The root protection of Capture 2EC and Regent 4SC was poor at each location in 2005. As discussed previously, Poncho 1250 proved inconsistent with root pruning exceeding one node at the Urbana site. The YieldGard Rootworm treatment at Monmouth provided excellent root protection throughout the growing season. Root pruning was more severe in the YieldGard Rootworm treatment in DeKalb (0.7) by late July. In Urbana, root injury was minimal (0.19) in the YieldGard Rootworm treatment through mid-July.

## Late-Season Root Protection

In 2004, we observed greater than expected late-season root injury in the YieldGard Rootworm treatment (MON 863) Golden Harvest H-8588RW (Gray and Steffey 2005). Therefore, in 2005, we selected a subset of treatments to evaluate root protection in July and again in August at DeKalb, Monmouth, and Urbana (Table 3). These treatments included Aztec 2.1G, Force 3G, Poncho 1250, YieldGard Rootworm (RX 718 YGPL-RW/CB), and the control. As observed in 2004, late-season pruning of brace roots occurred once again. This observation was most obvious for Aztec 2.1G (DeKalb), Force 3G (Urbana), and the YieldGard Rootworm treatment (Urbana).

At the DeKalb location (planting date—April 27), root injury increased marginally in the Poncho 1250 (0.78 to 0.83) and YieldGard Rootworm (0.70 to 0.87) treat-

**Table 1. Root ratings[1,2] for corn rootworm products, DeKalb, Monmouth, and Urbana, University of Illinois, 2005**

| Products | Rate[3,4] | Placement | DeKalb[5] | Monmouth[6] | Urbana[7] |
|---|---|---|---|---|---|
| Aztec 4.67G[8] | 3.0 | Furrow | 0.22 ef | 0.17 i | 0.33 efg |
| Aztec 2.1G | 6.7 | Band | 0.29 ef | 0.48 f–i | 0.32 efg |
| Aztec 2.1G + Poncho 250[9] | 6.7 | Band | 0.18f | 0.32 hi | 0.27 efg |
| Aztec 2.1G + Poncho 1250[10] | 4.0 | Band | 0.28 def | 0.30 i | 0.3 efg |
| Capture 2EC | 0.37 | Band | 1.44 b | 0.99 e–h | 1.46 b |
| Counter 15G | 8.0 | Band | Not included | 0.13 i | 0.45 efg |
| Defcon 2.1G | 6.7 | Band | 0.36 def | Not included | 0.22 fg |
| Defcon 2.1G | 6.7 | Furrow | 0.23 ef | Not included | 0.28 efg |
| Force 3G[8] | 4.0 | Band | 0.38 def | 0.41 ghi | 0.52 d–g |
| Force 3G | 4.0 | Band | 0.47 def | 0.41 ghi | 0.48 d–g |
| Fortress 5G[8] | 4.0 | Furrow | 0.36 def | 0.33 hi | 0.14 g |
| Fortress 2.5G | 8.0 | Furrow | 0.2 f | 0.37 hi | 0.2 fg |
| Lorsban 15G | 8.0 | Band | 0.29 def | 0.46 ghi | 0.66 de |
| Lorsban 4E | 2.4 | Band | 0.49 def | 0.26 i | 0.91 cd |
| Lorsban 75 WG | 1.2 | Band | 1.4 bc | 0.48 f–i | 1.33 bc |
| Nufos 15G | 8.0 | Band | 0.31 def | 0.35 hi | 0.53 def |
| Poncho 1250 | 1.25 | Seed treatment | 0.78 cd | 0.55 f–i | 1.21 bc |
| Regent 4SC | 0.24 | Microtube, in-furrow | 1.64 b | 1.53 b–e | 2.25 a |
| YGRW[11] | Transgenic seed | | 0.7 de | 0.04 i | 0.19 fg |
| Check | | | 2.37 a | 2.25 a | 2.32 a |

[1] Root ratings are based upon the 0 to 3 root-rating scale developed by Oleson et al. (2005): 0.00, no feeding damage; 1.0, one node (circle of roots), or the equivalent of an entire node, pruned back to within approximately 3.8 cm (1.5 in.) of the stalk (or soil line if roots originate from aboveground nodes); 2.0, two complete nodes pruned; and 3.0, three or more complete nodes pruned (highest rating that can be given).

[2] Means followed by same letter do not significantly differ within a column ($P = 0.05$, Duncan's new multiple range test).

[3] Rates of application for band and in-furrow placements are ounces per 1,000 feet of row.

[4] Rates of application for seed treatments are milligrams of active ingredient per seed.

[5] Planting date was 27 April 2005 into a trap crop (late-planted corn interplanted with pumpkins); root evaluation date was 26 July 2005.

[6] Planting date was 28 April 2005 into a trap crop (late-planted corn interplanted with pumpkins); root evaluation date was 25 July 2005.

[7] Planting date was 3 May 2005 into a trap crop (late-planted corn interplanted with pumpkins); root evaluation date was 13 July 2005.

[8] Applied using modified SmartBox metering units.

[9] Poncho applied at 0.25 mg (AI)/seed.

[10] Poncho applied at 1.25 mg (AI)/seed.

[11] Hybrid used for both trials was YieldGard RW (RX 718 YGPL-RW/CB). All other treatments were applied to the nontransgenic isoline.

ments from 26 July (first root evaluation date) to 15 August (second evaluation date). By mid-August, nearly a full node of brace roots had been destroyed in both of these treatments. Very noticeable increases in root injury occurred in the Aztec 2.1G (0.29 to 0.81) and Force 3G (0.47 to 0.74) treatments at the DeKalb site. In Urbana (planting date 3 May), only slight increases in root injury were noted for Aztec 2.1G (0.32 to 0.50) and Poncho 1250 (1.21 to 1.43) from 13 July to 11 August. However, considerably more root pruning was observed in the Force 3G (0.48 to 0.95) and YieldGard Rootworm (0.19 to 0.74) treatments from 13 July to 11 August. At Monmouth (planting date 28 April) insignificant

**Table 2. Precipitation totals (inches) for DeKalb, Monmouth, and Urbana, from April through August 2005**

| Months | DeKalb | Monmouth | Urbana |
|---|---|---|---|
| April | 1.37 | 2.78 | 3.98 |
| May | 2.08 | 2.15 | 0.97 |
| June | 2.87 | 2.07 | 2.42 |
| July | 1.86 | 1.58 | 4.30 |
| August | 3.36 | 3.09 | 2.26 |
| Totals | 11.54 | 11.67 | 13.93 |

**Table 3. Root ratings[1,2] for selected corn rootworm products, DeKalb, Monmouth, and Urbana, at early and later evaluation dates, University of Illinois, 2005**

| Products | Rate[3,4] | Placement | DeKalb[5] 1st Dig | DeKalb[6] 2nd Dig | Monmouth[7] 1st Dig | Monmouth[8] 2nd Dig | Urbana[9] 1st Dig | Urbana[10] 2nd Dig |
|---|---|---|---|---|---|---|---|---|
| Aztec 2.1G | 6.7 | Band | 0.29 ef | 0.81 b | 0.48 f–i | 0.24 b | 0.32 efg | 0.50 c |
| Force 3G | 4.0 | Band | 0.47 def | 0.74 b | 0.41 ghi | 0.38 b | 0.48 d–g | 0.95 bc |
| Poncho 1250[11] | 1.25 | Seed treatment | 0.78 cd | 0.83 b | 0.55 f–i | 0.32 b | 1.21 bc | 1.43 b |
| YGRW[12] | Transgenic seed | | 0.70 de | 0.87 b | 0.04 i | 0.08 b | 0.19 fg | 0.74 bc |
| Check | | | 2.37 a | 2.10 a | 2.25 a | 2.19 a | 2.32 a | 2.42 a |

[1] Root ratings are based upon the 0 to 3 root-rating scale developed by Oleson et al. (2005): 0.00, no feeding damage; 1.0, one node (circle of roots), or the equivalent of an entire node, pruned back to within approximately 3.8 cm (1.5 in.) of the stalk (or soil line if roots originate from aboveground nodes); 2.0, two complete nodes pruned; and 3.0, three or more complete nodes pruned (highest rating that can be given).

[2] Means followed by same letter do not significantly differ within a column ($P = 0.05$, Duncan's new multiple range test).

[3] Rates of application for band and in-furrow placements are ounces per 1,000 feet of row.

[4] Rates of application for seed treatments are milligrams of active ingredient per seed.

[5] Planting date was 27 April 2005 into a trap crop (late-planted corn interplanted with pumpkins); root evaluation date was 26 July 2005.

[6] Planting date was 27 April 2005 into a trap crop (late-planted corn interplanted with pumpkins); root evaluation date was 15 August 2005.

[7] Planting date was 28 April 2005 into a trap crop (late-planted corn interplanted with pumpkins); root evaluation date was 25 July 2005.

[8] Planting date was 28 April 2005 into a trap crop (late-planted corn interplanted with pumpkins); root evaluation date was 15 August 2005.

[9] Planting date was 3 May 2005 into a trap crop (late-planted corn interplanted with pumpkins); root evaluation date was 13 July 2005.

[10] Planting date was 3 May 2005 into a trap crop (late-planted corn interplanted with pumpkins); root evaluation date was 11 August 2005.

[11] Poncho applied at 1.25 mg (AI)/seed.

[12] Hybrid used for both trials was YieldGard RW (RX 718 YGPL-RW/CB). All other treatments were applied to the nontransgenic isoline.

differences in root protection were noted among the treatments, including YieldGard Rootworm, from 25 July to 15 August. Expected variation in root injury within a treatment alone may account for the smaller numerical differences in averages that were observed from the first to the second dig for some products.

## YieldGard Rootworm Hybrid Evaluation Trial

In 2005, with the cooperation of Monsanto Company, we evaluated the root protection offered by nine YieldGard Rootworm (MON 863) hybrids and a check (nontransgenic hybrid) that were all planted on 29 April (four-row plots, 45 ft in length, four replicates) into a plot area that had been planted to a trap crop (late-planted corn intercropped with pumpkins) in 2004. Roots were dug and rated (ten roots for each replicate by treatment combination) for injury on 20 July and 10 August (Table 4). A replicate of the entire experiment also was planted on 23 May. Because the root injury was so minimal in the experiment planted in late May, we report only the results from the 29 April study. All hybrids were selected by Monsanto Company, and we rated them without any knowledge of their genetic background. As of October 2005, the identity of these hybrids remains unknown to us.

Root injury in the check treatment was significant with two nodes of roots destroyed (2.09, 20 July). As of 20 July, the root protection afforded by hybrids A (0.47), B (0.39), E (0.16), F (0.19), H (0.2), and I (0.21) was very good to excellent. YieldGard Rootworm hybrids A, B, E, F, H, and I were commercialized in 2005. By 10 August, root ratings were generally greater in these hybrids; however, we suggest the increases were not of biological significance. Hybrids E and H are the same hybrids. This information was revealed to us by Monsanto Company after we had concluded our root evaluations. Root pruning in YieldGard Rootworm hybrids C (0.98, 20 July; 1.27, 10 August) and D (0.78, 20 July; 0.98, 10 August) was excessive with nearly one node of roots destroyed in each hybrid. Monsanto Company indicated that they were not surprised by these results because both of these transgenic hybrids had failed their in-house screens during 2004. Neither of these hybrids were moved into the commercialization phase. Of surprise to Monsanto Company was the lackluster performance of hybrid G, which was commercialized in 2005 and had considerable brace root pruning by 20 July (0.75, ¾ node destroyed) and 10 August (0.93, approximately 1 node destroyed). Hybrid G had undergone and in-house screen. These results suggest that some variation in root protection exists among YieldGard Rootworm (MON 863) hybrids. We hope to continue this research with Monsanto Company during the 2006 growing season.

## Plant Growth Stages and Expression of the Cry3Bb1 Protein

At the conclusion of our field season in 2004, we raised several questions with regard to the performance of YieldGard Rootworm hybrids. These same questions

**Table 4. Root ratings[1,2] for YieldGard (MON 863) corn rootworm hybrids (A–I) evaluation trial, University of Illinois, Urbana[3], 2005**

| Root evaluation dates | A | B | C | D | E | F | G | H | I | Check |
|---|---|---|---|---|---|---|---|---|---|---|
| 20 July | 0.47 c | 0.39 c | 0.98 b | 0.78 b | 0.16 def | 0.19 de | 0.75 b | 0.2 d | 0.21 d | 2.09 a |
| 10 Aug. | 0.73 c | 0.4 d | 1.27 b | 0.98 c | 0.25 de | 0.38 d | 0.93 c | 0.19 def | 0.38 d | 1.91 a |

[1] Root ratings are based upon the 0 to 3 root-rating scale developed by Oleson et al. (2005): 0.00, no feeding damage; 1.0, one node (circle of roots), or the equivalent of an entire node, pruned back to within approximately 3.8 cm (1.5 in.) of the stalk (or soil line if roots originate from aboveground nodes); 2.0, two complete nodes pruned; and 3.0, three or more complete nodes pruned (highest rating that can be given).

[2] Means followed by same letter do not significantly differ within a row (P = 0.05, Duncan's new multiple range test).

[3] All YieldGard Rootworm hybrids (MON 863) were planted on 29 April 2005.

can be directed at the recently registered (fall 2005) transgenic corn rootworm hybrids (Herculex RW) that will be commercialized for the first time in 2006.

- Does the expression of the Cry3Bb1 (YieldGard Rootworm) or Cry 34Ab1 and Cry 35Ab1 proteins (Herculex RW) diminish as the season progresses, compromising root protection in late July and early August?
- Do early planting dates compromise the root protection of transgenic rootworm hybrids?
- Are there critical differences in expression of *Bacillus thuringiensis* (Bt) proteins in root tissue across hybrids?
- Are some hybrids with less than satisfactory root architecture poor candidates for the transgenic rootworm technology?
- Do differences in soil nitrogen levels influence the expression of Bt proteins in root tissue?

In an issue of Crop Science (March 28, 2005), scientists (Vaughn et al. 2005) from Monsanto Company published an article (*A Method of Controlling Corn Rootworm Feeding Using a Bacillus thuringiensis Protein Expressed in Transgenic Maize*) in which they described the expression level of Cry3Bb1 (Bt protein targeted against corn rootworm larvae) in five corn hybrids (MON 863) at two growth stages (V4 and V9) in a growth chamber study. The sample size for each hybrid was fourteen. Protein levels were determined by using an enzyme-linked immunosorbent assay (ELISA) technique. The entire root system at both V4 and V9 stages was used. No significant difference in expression level of the Cry3Bb1 protein due to hybrid was detected. Nor was there any significant interaction between hybrids and growth stages with respect to protein expression. Expression of the Cry3Bb1 protein in root tissue for each of the hybrids at the V4 stage was reported as hybrid 1, 60.21 ppm; hybrid 2, 61.98 ppm; hybrid 3, 69.67 ppm; hybrid 4, 75.17 ppm; and hybrid 5, 80.67 ppm. As corn plants reached the V9 stage, the expression of the Cry3Bb1 protein decreased across each of the five hybrids: hybrid 1, 49.34 ppm; hybrid 2, 40.50 ppm; hybrid 3, 42.88 ppm; hybrid 4, 42.33 ppm; and hybrid 5, 45.81 ppm. Averaged across each of the five hybrids for both plant stages, expression of the Cry3Bb1 protein decreased from 69.8 to 44.0 ppm. The lethal concentration ($LC_{50}$) of the Cry3Bb1 protein (necessary to kill 50% of a corn rootworm larval population) is estimated to be approximately 75 ppm (Dudin et al. 2001). The authors acknowledged that the effect of growth stage on the expression of the Cry3Bb1 protein was significant, on average declining by 25.8 ppm across hybrids from V4 to V9. Despite the decline in the expression of the Bt protein across all five hybrids (V4 to V9), the root protection afforded by each transgenic hybrid was excellent, with only minor feeding scars on the root systems reported. The control (nontransgenic hybrid) had over two nodes of roots completely destroyed.

***What are some potential implications of these findings?*** If a cool spring leads to a very late corn rootworm larval hatch (early to mid-June) and subsequent extended larval feeding period (late July through early August), we might anticipate more pressure being exerted on some transgenic corn rootworm hybrids. As we observed in our hybrid (MON 863) evaluation trial, some variation exists in root protection among transgenic corn rootworm hybrids. Very early planting (early April) of corn could exacerbate this situation. Transgenic corn rootworm hybrids also tend to delay development and emergence of male and female western corn rootworm adults (beetles) (Crowder et al. 2005). Delayed larval development in combination with declining levels of Bt proteins (in some transgenic rootworm hybrids) could result in more root injury, especially if corn rootworm densities are high.

## Susceptibility of Western Corn Rootworm First Instars to Cry3Bb1 Protein

In a recent journal article (*Journal of Economic Entomology*, August 2005), scientists (Siegfried et al. 2005) from the University of Nebraska and Monsanto Company published some very interesting data regarding the baseline susceptibility of western corn rootworm larvae to the CryBb1 (Bt) protein. They used neonate (newly hatched larvae) obtained from laboratory colonies as well as field populations. The first instars were exposed to increasing levels of the Cry3Bb1 protein (artificial diet) and mortality and growth were assessed after 4 to 7 d had elapsed. Field populations were collected from the following locations: 1) Yuma and Weld counties, Colorado; 2) Scott County, Iowa; 3) Iroquois and Warren counties, Illinois; 4) Gove County, Kansas; 5) Hamilton, Clay, and Seward counties, Nebraska; 6) Winona, Minnesota; 7) Ontario County, New York; and 8) Lancaster County, Pennsylvania. The authors offered the following comments in their results and discussion section: "The results of these bioassays suggest that western corn rootworm larvae are in general not

extremely sensitive to the Cry3Bb1 toxin because both $LC_{50}$ and $EC_{50}$ values are several orders of magnitude greater than values reported for lepidopteran-active Cry toxins by using similar bioassay methods. This lack of sensitivity is consistent with the designation of MON 863 as a low-to-medium dose product (EPA 2003)." The authors are to be commended for publishing this very important article. As they indicated in their article, the development of baseline susceptibility data is the "first step" in a monitoring program that is designed to pinpoint when levels of susceptibility in a corn rootworm population may begin to change in response to long term exposure to Bt proteins expressed in transgenic plants.

A review of this article revealed some interesting differences in susceptibility of western corn rootworm neonates from the two field populations collected in Illinois from Iroquois and Warren counties. The $EC_{50}$ values (concentration of Cry3Bb1 that produces 50% growth inhibition relative to untreated controls) for first instars of western corn rootworm collected from Iroquois and Warren counties were 2.80 ($n$ = 146, 95% CI = 2.22–3.50) and 0.98 ($n$ = 155, 95% CI = 0.76–1.24), respectively. These values refer to micrograms of Cry3Bb1 per square centimeter of artificial diet that has been treated. The $LC_{50}$ values (micrograms of Cry3Bb1 protein per square centimeter of treated artificial diet needed to kill 50% of neonates) for Iroquois and Warren counties were 4.22 ($n$ = 146, 95% CI = 1.99–6.75) and 0.74 ($n$ = 155, 95% CI = 0.32–1.14). In essence, it took nearly 3 times (3×) as much Cry3Bb1 protein to cause a 50% growth inhibition of first instars collected from Iroquois County compared with those from Warren County. Likewise, a concentration of Cry3Bb1 protein, nearly 6 times (6×) greater, was required to kill 50% of neonate western corn rootworm larvae obtained from Iroquois County compared with those from Warren County. Considerable speculation and discussion has occurred during the past 3 to 4 yr regarding a suspected increased vigor of variant western corn rootworms compared with nonvariant populations. Although these data do not necessarily confirm this suspicion, they do suggest that this hypothesis should be more carefully tested. Iroquois County lies within the geographical "heart" of the variant western corn rootworm population. This county has a strong corn and soybean rotation history, believed to be a partial explanation for the evolution of the variant western corn rootworm. Warren County, located in northwestern Illinois, has only recently become susceptible to variant western corn rootworm damage in rotated corn. This area of the state has a longer history of continuous corn production practices.

It also should be pointed out that among the 12 field populations of western corn rootworm larvae tested, the $EC_{50}$ values obtained from neonates in Iroquois County were the greatest. Interestingly, the $LC_{50}$ values for neonates exposed to the Cry3Bb1 protein from three other locations were greater than those obtained from larvae collected in Iroquois County (4.22) and include Weld County, Colorado (9.20) ($n$ = 321, 95% CI = 6.45–13.06); Gove County, Kansas (4.90) ($n$ = 320, 95% CI = 2.51–7.40); and Lancaster County, Pennsylvania (6.61) ($n$ = 289, 95% CI = 4.49–9.84).

We continue to learn more about the biology and ecology of the variant western corn rootworm and the responses of corn rootworms in general to the Cry3Bb1 protein. As new transgenic events are commercialized for this important corn insect pest there are sure to be unexpected occurrences.

## Concluding Remarks

In answer to our question contained in the title: "Does anything work on the variant western corn rootworm?"—the answer is "yes." In 2005, the granular soil insecticides performed very well in spite of intense corn rootworm pressure and dry soil conditions for much of the summer. We've discussed in previous years (Gray and Steffey 1998b) that any of the granular products may suffer from performance problems from time to time depending upon a number of variables such as early planting, poor calibration, intense larval densities, dry soil conditions, and lack of adequate incorporation of insecticide granules. With respect to the insecticidal seed treatments (nicotinoids) and liquids, lack of consistent performance under heavy corn rootworm pressure has been observed regularly in our efficacy trials conducted at the University of Illinois Research and Education Centers (DeKalb, Monmouth, and Urbana). Although our experience with transgenic corn rootworm hybrids has been much more limited (three commercial growing seasons), the overall performance of this exciting technology has been very good in our experiments. In the past 2 yr, we have observed some late-season pruning on some YieldGard Rootworm (MON 863) hybrids. In 2005, many Illinois' producers reported that they were very pleased with the vigor (plant height and color) of YieldGard Rootworm hybrids throughout July during the critical pollination period. We, too, made similar observations in several of our experiments. However,

if late-season pruning in some transgenic hybrids leads to lodging, harvest difficulties could ensue. As pointed out in this article, we also observed that root protection declined in some soil insecticides when roots were evaluated for injury in August.

In 2006, we anticipate a continued expansion of the variant western corn rootworm into southern Illinois. Producers who have never focused on this impressive insect pest of corn are encouraged to keep in mind that there is no "silver bullet" that works all the time. Ultimately, an integrated management approach (e.g., scouting, use of economic thresholds, soil insecticides, transgenic hybrids, and crop rotation) is key to sustain the various integrated pest management tools that can be used against corn rootworms.

## References


Crowder, D.W., D.W. Onstad, M.E. Gray, C.M.F. Pierce, A.G. Hager, S.T. Ratcliffe, and K.L. Steffey (2005) Analysis of the dynamics of adaptation to transgenic corn and crop rotation by western corn rootworm (Coleoptera: Chrysomelidae) using a daily time-step model. Journal of Economic Entomology 98: 534–551.

Dudin, Y.A., B.P. Tonnu, L.D. Albee, and R.P. Lirette (2001) Amended report for MSL 16599: B.t. Cry3Bb1.11098 and NPTII protein levels in tissue samples collected from corn event MON 863 grown in 1999 field trials. Report No. MSL-17181; an unpublished study conducted by Monsanto Company. Submitted to EPA on May 21, 2001, MRID 454240-01.

[EPA] Environmental Protection Agency. 2003. *Bacillus thuringiensis* Cry3Bb1 protein and the genetic material necessary for its production (vector zmir131) in event MON863 corn fact sheet. EPA Publication Number 730-F-03-01.

Gray, M.E., and K.L. Steffey (1998a) Corn rootworm (Coleoptera: Chrysomelidae) larval injury and root compensation of 12 maize hybrids: an assessment of the economic injury index. Journal of Economic Entomology 91: 723–740.

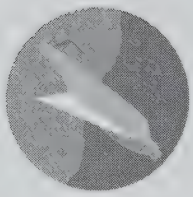
Gray, M.E., and K.L. Steffey (1998b) Soil insecticides and root protection: a sure thing, or a roll of the dice each season? pp. 24-28. *In* Proceedings of the Illinois Agricultural Pesticides Conference, Illinois Cooperative Extension Service, Urbana-Champaign.

Gray, M.E., and K.L. Steffey (2005) Transgenic YieldGard rootworm hybrid stumbles in Urbana experiment: Why? pp. 41-46. *In* Proceedings of the Illinois Crop Protection Technology Conference, University Illinois Extension, Urbana-Champaign.

Oleson, J.D., Y.K. Park, T.M. Nowatzki, and J.J. Tollefson (2005) Node-injury scale to evaluate root injury by corn rootworms (Coleoptera: Chrysomelidae). Journal of Economic Entomology 98: 1–8.

Siegfried, B.D., T.T. Vaughn, and T. Spencer (2005) Baseline susceptibility of western corn rootworm (Coleoptera: Chrysomelidae) to Cry3Bb1 *Bacillus thuringiensis* toxin. Journal of Economic Entomology 98: 1320–1324.

Vaughn, T., T. Cavato, G. Brar, T. Coombe, T. DeGooyer, S. Ford, M. Groth, A. Howe, S. Johnson, K. Kolacz, C. Pilcher, J. Purcell, C. Romano, L. English, and J. Pershing (2005) A method of controlling corn rootworm feeding using a *Bacillus thuringiensis* protein expressed in transgenic maize. Crop Science 45: 931–938.



# European Corn Borers: A Diminished Insect Threat from Now On?

RICHARD L. HELLMICH

## Introduction

Before the introduction of *Bacillus thuringiensis* (Bt) corn hybrids, a well-respected expert of European corn borers (*Ostrinia nubilalis*) once told me that the experimental Bt corn he saw was "bulletproof" to corn borers and more resistant to borer damage than any corn he had ever seen. Little did we know that this was the beginning of a revolution in corn insect management. Now, Bt corn is planted across the Corn Belt and in many countries around the world. In 2005, nearly 11 million hectares (28 million acres) of Bt corn was planted in the United States (35% of total). High percentages of Bt corn were planted in Illinois (30%) and states west of Illinois: Iowa (46%), Minnesota (44%), Missouri (43%), Kansas (33%) and Nebraska (51%; USDA–NASS 2005). In some regions that have a history of high *O. nubilalis* damage, more than 50% of the corn planted was Bt corn.

This year (2006) will be the 10-year anniversary of the introduction of Bt corn hybrids, and many scientists are starting to question whether Bt corn is influencing corn borer populations. There is evidence that Bt cotton has suppressed populations of the pink bollworm in Arizona (Carrière et al. 2003), but these insects are ecological specialists on cotton. Corn borers have many alternate hosts (Hodgson 1928), so could the same type of areawide suppression of European corn borers occur? To informally address this question, I have interviewed several corn borer experts, who have volunteered much anecdotal information and some empirical data. Also, I report multiyear trap data from two locations in Iowa.

## Anecdotal Evidence

All the scientists I interviewed from Illinois and states west of Illinois (Iowa, Missouri, Minnesota, Nebraska, and Kansas) suggested corn borer populations have been lower in the past 3 to 5 years compared with years before the introduction of Bt corn. Numbers of corn borers caught in traps are well below historical means. Scientists in Iowa and Nebraska noted that before the introduction of Bt corn hybrids light traps during peak times often caught thousands of corn borer moths per night, but now these same traps rarely catch more than a hundred moths per night. Two scientists reported they have encountered fewer "moth storms" (dozens or even hundreds of moths hitting a vehicle windshield) in the night while driving in areas planted with corn. One extension expert noted that he had received calls from crop consultants to review scouting methods for corn borer damage. Presumably, these consultants had seen so little corn borer damage recently they were out of practice. All these scientists noted that corn borer populations still fluctuated from year to year but at greatly reduced numbers.

Scientists I interviewed in the eastern states (Pennsylvania, New York, Maryland, and Virginia) were divided with their responses. Corn borers historically have not been a major pest of field corn in New York and Virginia, so growers have not used high percentages of Bt corn. Accordingly, populations of corn borers have not noticeably changed. Pennsylvania has seen high adoption of Bt corn in some areas, but corn borer populations still remain high, perhaps because of the highly fragmented landscape that could support alter-

nate hosts or pockets of high corn borer populations. One of the most informative corn borer data sets comes from Maryland. In 1973, Dr. Galen Dively from the University of Maryland initiated a light-trapping program for several agricultural pests in eight regions of Maryland. Data from these continuous trappings suggest that in areas where Bt corn hybrids are high the corn borer populations are well below their historical means. Yet, populations of moths not impacted by Bt corn remain near their historical means. In contrast, in areas where Bt corn use is low, corn borer populations are still near historical means. A testimonial from a Maryland pepper grower further supports these observations. Corn borers are an important pest of peppers, but since this grower has rotated with Bt field corn, he has been able to reduce insecticidal applications for his pepper crop. He is convinced the Bt field corn he annually rotates with peppers has lead to a reduction of corn borer pressure on his pepper plants.

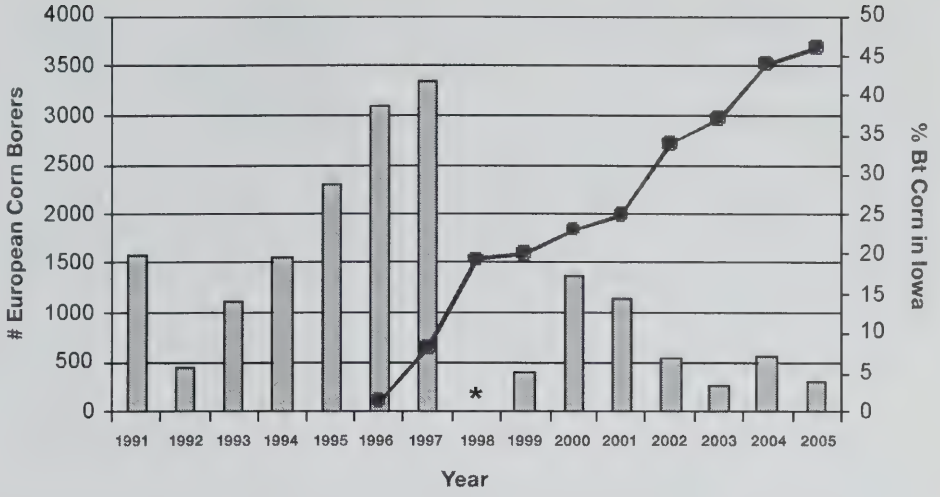



**Figure 1. Number of European corn borer moths captured in light traps at the Iowa State University Uthe Farm from 1991 to 2005.** Data represent female moths captured for 10 days during the peak of the second generation flight. Percentage of Bt corn planted in Iowa is denoted on the secondary axis (USDA–NASS June Planting Reports; e.g., USDA–NASS 2005). Bars represent European corn borers; line represents Bt corn percentages. Asterisk indicates data were not collected. Data is courtesy of Jean Dyer.

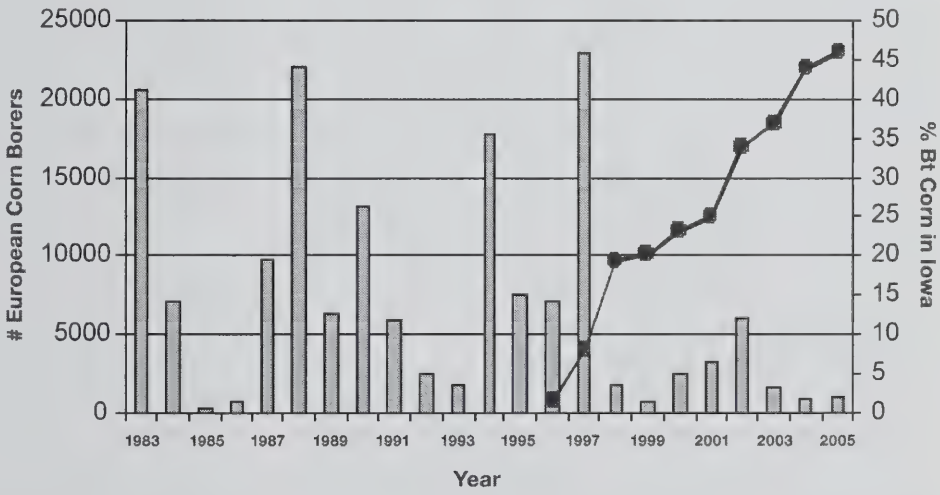



**Figure 2. Number of European corn borer moths captured in light traps near Slater, IA, from 1983 to 2005.** Percentage of Bt corn planted in Iowa is denoted on the secondary axis (USDA–NASS June Planting Reports). Bars represent European corn borers; line represents Bt corn percentages. Data is courtesy of Dr. Von Kaster.

## Empirical Evidence

Jean Dyer, a technician with the Corn Insects and Crop Genetics Research Unit in Ames, IA, has used light traps from four locations to capture corn borers for repopulating a laboratory colony. Her data from one location (other data sets are similar) suggest corn borer populations in the past 7 years have been much lower than previous years (Fig. 1). Also, Dr. Von Kaster has maintained a light trap near his research facilities in Slater, IA, since 1983. These data suggest corn borer populations varied dramatically from 1983 to 1997, but after 1997 the populations, although still variable, were much lower than the years before high use of Bt corn (Fig. 2).

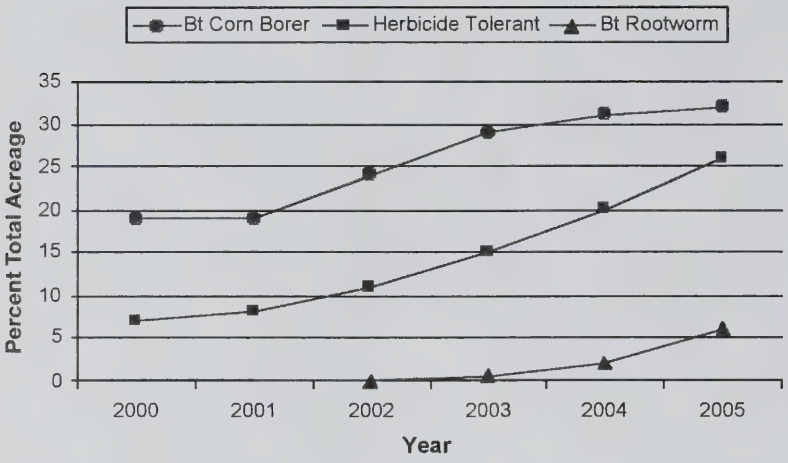



**Figure 3. Percentage of total acreage of genetically engineered corn hybrids (Bt corn borer, herbicide tolerant, and Bt rootworm) planted in the United States from 2000 to 2005.**

Other phenomena that could influence corn borer populations are weather, pathogens, or interactions of these factors. Wet springs could lead to late planting of corn and result in corn borer adults emerging before corn. In areas with few alternate hosts, this could lead to population declines. Also, hard rains during corn borer oviposition periods could have the same effect. The influence of such events on pathogens is unknown, but the possibility of epizootics cannot be ruled out. Yet, the trend for lower corn borer populations seems to have occurred in areas widely separated, both in and out of the Corn Belt. Weather or pathogen influences probably under most circumstances would be localized and not so widespread.

## Summary

The use of "corn borer" Bt hybrids is likely to remain at high percentages and could even increase. The increasing use of "rootworm" Bt hybrids and herbicide-tolerant hybrids will likely influence the use of corn borer Bt hybrids (Fig. 3), especially if these products are stacked. Currently a 20% non-Bt refuge is mandated as a strategy to manage corn borer resistance to Bt toxins. There is the possibility that future corn hybrids will express two or more genes with different modes of action that target Lepidoptera. Such pyramided hybrids might require less refuge, which could lead to even lower populations of European corn borer. At some point, a grower may want to consider whether the cost of Bt technology is justified.

None of the scientists I interviewed were ready to say an areawide suppression of European corn borers is definitely because of Bt corn. But, if current low corn borer population trends continue, it is likely the relationship of Bt corn and low corn borer populations will become more accepted.

## Acknowledgments

Thanks are extended to Dr. Von Kaster (Syngenta Seeds, Slater, IA) and Jean Dyer (USDA–ARS, Corn Insects and Crop Genetics Research Unit) for providing the European corn borer trap data. Mention of a proprietary product does not constitute an endorsement or a recommendation for its use by USDA.

## References

Carrière, Y., C. Ellers-Kirk, M. Sisterson, L. Antilla, M. Whitlow, T. J. Dennehy, and B. E. Tabashnik. 2003. Long-term regional suppression of pink bollworm by *Bacillus thuringiensis* cotton. Proceedings of the National Academy of Sciences USA 100: 1519–1523.

Hodgson, B. E. 1928. The host plants of the European corn borer in New England. USDA Technical Bulletin Number 77.

[USDA–NASS]U.S. Department of Agriculture–National Agricultural Statistics Service. 2005. Crop production: acreage supplement, pp.24-25. USDA–NASS, Washington, DC. http://usda.mannlib.cornell.edu/reports/nassr/field/pcp-bba/acrg0605.pdf.

# Corn and Soybean Rotations: Where to from Here?

GARY SCHNITKEY

In recent years, Illinois farmers have shifted acres from soybean to corn, resulting in a move away from traditional ½ corn–½ soybean rotations having 50% of the acres in corn and 50% of the acres in soybean to rotations that have more corn, such as ⅔ corn–⅓ soybean, ¾ corn–¼ soybean, and even continuous corn rotations. Much of the reason for this shift is the increasing economic attractiveness of corn relative to soybean. However, large increases in variable costs may change rotations. Because costs have increased more for corn than for soybean, the profitability of corn has decreased relative to soybean, which may cause a slowing of the movement of soybean acres to corn acres. There may even be a movement to more soybean acres in Illinois.

In this article, perspectives on the economics associated with corn–soybean rotations are provided by first showing how Illinois acres have shifted over time. This analysis shows that corn acres have increased between 2002 and 2005. Three factors can explain this shift: 1) increases in corn profits relative to soybean profits caused by relative yield changes, 2) increases in risks associated with soybean production, and 3) decreases in returns of corn-after-soybean production compared with corn-after-corn production. Finally, budgets are presented showing how recent variable costs have affected rotation decisions.

## Shifting Corn and Soybean Acres

The 1995 Farm Bill, often known as "Freedom to Farm," eliminated set-aside requirements and acreage constraints, thereby allowing farmers to plant whatever amounts of grains and forages they desired. Since passage of this bill, total acres devoted to combined corn and soybean production have increased slightly. Corn and soybean acres have exceeded 21 million acres every year since 1997, with the low being 21 million acres in 1997 and the high being 21.6 million acres in 2005 (Figure 1). The slight increase in corn and soybean acres has come largely at the expense of wheat acres. Total acres devoted to corn and soybean production represent more than 90% of the planted acres in Illinois. Hence, increases in corn production cause a reduction in soybean production and vice versa.

Over time, there have been changes in corn acres relative to soybean acres in Illinois. In 1987, the corn-to-soybean acre ratio was 1.26, meaning that there were 1.26 acres of corn for every acre of soybean (National Agricultural Statistical Service). From 1985 to 1998, the corn-to-soybean acre ratio generally trended downward (Figure 2). In 1998, the ratio was 1.00, meaning that there was 1 acre of corn to 1 acre of soybean in Illinois. This ratio of 1.00 is consistent with a ½ corn–½ soybean rotation being the predominant rotation.

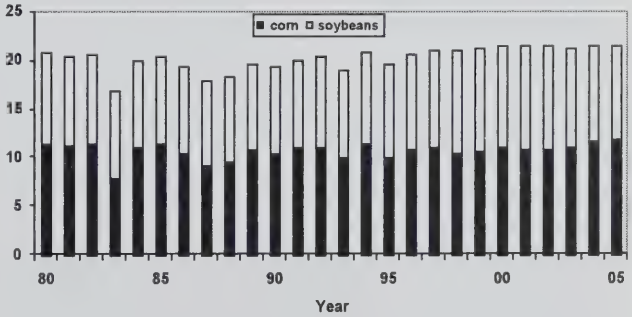



**Figure 1. Corn and soybean acres in Illinois, 1980 through 2005.**

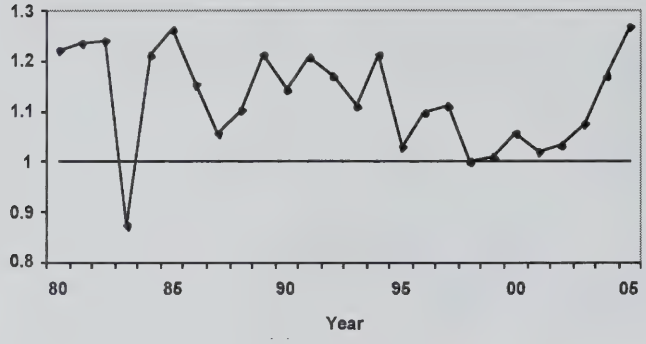



**Figure 2. Corn acres divided by soybean acres, Illinois, 1980 through 2005.**

Source: National Agricultural Statistical Service, U.S. Department of Agriculture

Since 1998, the corn-to-soybean acre ratio has generally trended up. The ratio was 1.03 in 2002, 1.07 in 2003, 1.17 in 2004, and 1.27 in 2005. These higher ratios mean that some farmers are moving away from ½ corn–½ soybean rotations and planting some corn on acres planted in the previous year to corn (i.e., corn-after-corn). Given constant total acres in corn and soybean, a 1.27 ratio roughly means that for every corn acre that followed soybean, there was 0.27 acres of corn following corn in 2005.

## Reasons for the Shift

Recent shifts to corn are likely caused by three factors: 1) increases in the profitability of corn relative to soybean, 2) increase in the risk of soybean production, and 3) decreases in relative returns of corn-after-soybean production compared with corn-after-corn production.

***Increasing corn returns relative to soybean returns:*** Recently, profits from corn have been higher than from soybean. For central Illinois, high-productivity farmland, corn revenue less variable costs exceeded soybean returns by $75 per acre in 2003 and $36 per acre in 2004 (Lattz and Schnitkey 2005). These 2003 and 2004 return differences compare with an average difference of $9.56 per acre between 1996 and 2002. Higher relative corn profits encourage more corn production and less soybean production.

The most important factor contributing to increasing corn returns has been higher corn yields relative to soybean yields. This trend can be illustrated by corn–soybean yield ratios that equal corn yield divided by soybean yield. In Illinois, the corn–soybean yield ratio averaged 3.2 from 1972 through 2000 (Figure 3). Since 2000, the yield ratio has been below 3.2 only in 2002. Even in 2002, much of the state had ratios above 3.2. The 2002, Illinois yield ratio was below 3.2 because of low ratios in southern and eastern Illinois. In 2003, the yield ratio hit an all-time high of 4.56. Illinois yields in 2004 were at record high levels for both corn and soybean (180 bushels for corn and 49 bushels for soybean). Even though soybean yields were at record levels, the corn–soybean yield ratio still favored corn. The 2004 yield ratio was 3.67, the second highest ratio on record.

Drought-reduced 2005 yields of 145 bu for corn and 45 bu for soybean give a ratio of 3.2 (Illinois Agricultural Statistical Service 2005). Historically, droughts have resulted in low ratios. For example, corn–soybean yield ratios were 2.7 in 1988, 2.8 in 1991, 3.0 in 1993, and 2.9 in 1995. The drought-reduced 2005 corn-soybean yield ratio is higher than in previous droughts which may indicate that the 2005 drought was not as severe as previous droughts. Alternatively, improved corn hybrids may not suffer as much as in previous droughts. Further analysis of 2005 yields from individual farms will shed light on this issue.

***Increasing soybean yield risks:*** If profits remain constant across crops, an increase in the risk of a crop will reduce the desirability of producing the crop, potentially leading to reductions in acres devoted to that crop. For many years, soybean was viewed as a "safe" crop, with yields not exhibiting as much variability as corn yields. For example, the minimum and maximum soybean yield for the state of Illinois between 1991 through 2002 differed by 6.5 bu per acre. During this same period, corn yields ranged by 43 bu, considerably more than soybean.

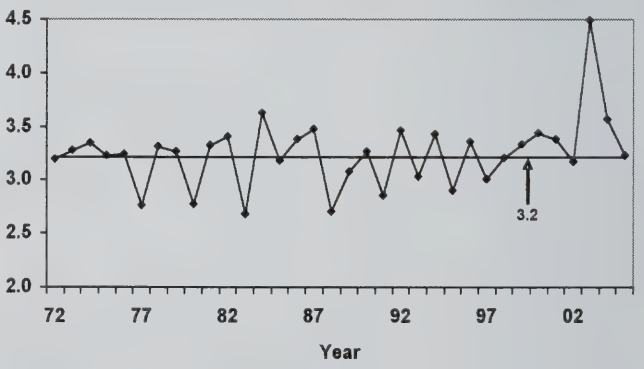



**Figure 3. Corn–soybean yield ratios, Illinois, 1972–2005.**

The perception that soybean was a safe crop began to change in 2003. In that year, soybean yields in Illinois averaged 36.5 bu, considerably below the trend-line yield of 43.5 bu. The previous time, soybean yields had been reduced to this level was in 1991 when yields averaged 37.5 bu.

The low 2003 yield was followed the next year by the announced introduction of Asian soybean rust in southern United States. Finding rust increased the probability that rust could reach Illinois. If soybean rust reaches Illinois, it has the potential to increase costs and reduce yields, in some cases by more than 10 bu per acre if not treated properly with fungicides. Although rust did not reach Illinois in 2005, there was the potential that it could reach Illinois when acreage decisions were being made. Moreover, there is the chance that rust could occur in 2006 and following years.

Both the low 2003 yield and soybean rust introduction increased the perceived risk of soybean production. A similar increase in risk did not occur for corn. Hence, soybean risks increased relative to corn risks, causing a reduction in the incentives to plant soybean.

***Decreases in returns of corn-after-soybean production compared with corn-after-corn production:*** Traditionally, corn-after-corn production has lower returns than corn-after-soybean production. In recent years, however, difference in returns has narrowed. Up to several years ago, insecticide applications were not generally required for corn-after-soybean production. However, rootworms have adapted to overwinter as eggs in the soil of soybean fields in east central Illinois, requiring some sort of control similar to corn-after-corn production. This control, either through insecticides or resistant hybrids, costs in the $5 to $10 per acre range, and used to be an advantage to corn-after-soybean production.

Another major advantage for corn-after-soybean production has been a yield drag for corn-after-corn production. Agronomic research convincingly indicates that corn-after-corn production averages 10% less than corn-after-soybean production (Crooksten et al. 1991, Meese et al. 1991, Porter et al. 1997, Pederson et al. 2003). However, some farmers do not believe that there is a yield drag for corn-after-corn.

Whether or not yield drag exits, perceptions of yield drag are important to planting decisions. Often, a 10% yield drag causes corn-after-corn production to be unattractive compared with soybean production. In many cases, not having a yield drag causes corn-after-corn production to be more profitable than soybean production. If farmers do not believe a drag exists, they will more likely favor corn production.

## Variable Cost Increases

The aforementioned factors generally increase the attractiveness of corn production relative to soybean production. Recent increases in variable costs may change relative profits. Recently, energy costs have increased dramatically, causing fertilizers and fuel prices to rise. Within fertilizers, nitrogen costs have been the most affected. Because nitrogen is not used on soybean and because fuel use is more intensive in corn than on soybean, cost increases have been higher for corn than for soybean. Estimates are that variable costs for corn will be $55 per acre higher in 2006 than in 2002, whereas soybean costs are projected to be $20 per acre higher in 2006 than in 2002 (Schnitkey and Lattz 2005b). These cost increases decrease corn profitability relative to soybean profitability.

## Budgets

Impacts of the aforementioned factors can be evaluated using budgets. Table 1 shows budgets for corn-after-soybean, corn-after-corn, and soybean for central Illinois farms having high productivity farmland. Results for 2003 and 2004 are based on data summarized for farms enrolled in Illinois Farm Business Farm Management (FBFM). Corn-after-soybean and soybean budgets are taken directly from FBFM records. Two modifications are made to corn-after-soybean budgets to get corn-after-corn budgets: 1) yields are reduced for corn-after-corn production and 2) costs are increased for corn-after-corn production to account for additional nitrogen needs. Budgets for 2005 and 2006 are projections.

All budgets show revenue from crop sales and loan deficiency payments and expenses for variable items (fertilizer, seed, pesticides, drying and storage, machinery repair, machinery hire, and fuel). Not shown is revenue from direct and counter-cyclical payments as well as costs for fixed items such as machinery depreciation, labor, and interest. These items are not shown because they do not vary if a different crop is planted.

In 2003, crop revenue less variable costs, hereafter referred to as returns, were $246 for corn-after-soybean, $204 for corn-after-corn, and $153 for soybean (Table 1). In this year, corn had high yields, whereas soybean had poor yields. As a result, corn had significantly

higher returns than soybean. In this year, corn-after-soybean and corn-after-corn had higher returns than soybean.

In 2004, corn also was more profitable than soybean. Corn-after-soybean had returns of $255, corn-after-corn had returns of $224, and soybean returns were $219 per acre. This year was characterized by high yields that resulted in high returns for both corn and soybean.

Note, however, that the most profitable rotation was ½ corn–½ soybean having a return of $237 per acre, compared with returns of $233 and $224 per acre, respectively, for ⅔ corn–⅓ soybean and continuous corn. Rotations with more corn were less profitable because there were fewer acres in the higher return corn-after-soybean "crop" and more acres in the corn-after-corn "crop". Rotation returns shown in Table 1 are calculates assuming that a stable rotation was reached. Hence, the ⅔ corn–⅓ soybean rotation has one-third of its acres in corn-after-soybean, ⅓ in corn-after-corn, and ⅓ in soybean. The continuous corn rotation has all its acres in corn-after-corn.

Projected 2005 returns have soybean as the most profitable crop. Corn-after-soybean has a return of $156 per acre, and soybean had a return of $162. Corn yields are projected to take a larger percentage decline from trend-line yields than soybean. In addition, variable costs have increased from the previous year, with corn-after-soybean costs rising from $193 per acre up to $206 per acre, an increase of $13 per acre. Soybean costs increase a lesser amount of $6 per acre, from $112 per acre up to $118 per acre. As a result of soybean being the most profitable crop, rotations with higher amounts of soybean in the rotation were more profitable.

Projected returns for 2006 are for corn-after-soybean and soybean to be roughly equal in profits. Corn-after-soybean has projected returns of $160 per acre, whereas soybean has returns of $159 per acre. Five-year average yields are used in these budgets and prices are based on futures prices during the middle of October 2005. Soybean has become more closely aligned with corn because of the cost increases.

The cost increases have diminished the advantage that has come from increasing relative yields of corn. The 2006 projected yields result in a corn–soybean yield ratio of 3.4 (170-bu corn yield/50-bu soybean yield), significantly above the state long-run average of 3.2. If costs were at 2003 levels, corn production would be more profitable than soybean production. The cost increases have largely negated the advantage that corn had from increasing relative yields.

The aforementioned analysis was done with averages for central Illinois high-productivity farmland. Farms differ in terms of corn returns relative to soybean returns (Schnitkey and Lattz 2005a). Hence, farms should evaluate cropping decisions given their own unique history of yields and prices.

## Summary

Before 2005, the incentives to plant corn have been increasing because 1) corn profits have increased relative to soybean profits, 2) soybean production has become more risky, and 3) pest control advantages of corn-after-soybean production over corn-after-corn production have been reduced. Recent cost increases counter the above-mentioned three advantages for corn production. Current 2006 projections for central Illinois high productivity farmland suggest that soybean production will be as profitable as corn production.

Cost increases will reduce incentives to switch acres from soybean to corn. Hence, it is unlikely that corn acres relative to soybean acres will increase in 2006. There may even be an increase in soybean acres in Illinois.

## References


Crookston, R.K., J.E. Kurle, P.J. Copeland, J.H. Ford, and W.E. Lueschen (1991) Rotational cropping sequence affects yield of corn and soybeans. Agronomy Journal 83: 108–113.

Illinois Agricultural Statistical Service, U.S. Department of Agriculture (2005) October Crop report (http://www.agstats.state.il.us/releases/crop.pdf).

Lattz, D., and G. Schnitkey (2005) Historic crop costs form Illinois FBFM farms database tool (http://www.farmdoc.uiuc.edu/manage/enterprise_cost/crop_revenue_less_variable_cost.html#).

National Agricultural Statistical Service, U.S. Department of Agriculture (2005) Quick stats: agricultural statistical data base (http://www.nass.usda.gov/QuickStats/).

Meese, B.G., P.R. Carter, E.S. Oplinger, and J.W. Pendleton (1991) Corn/soybean rotation effect as influenced by tillage, nitrogen, and hybrid/cultivar. Journal of Production Agriculture 4: 74–80.

Pederson, P., and J.G. Lauer (2003) Corn and soybean response to rotation sequence, row spacing, and tillage system. Agronomy Journal 95: 965–971.

**Table 1. Budgets for Central Illinois Corn and Soybean Production**

| | 2003 | | | 2004 | | |
|---|---|---|---|---|---|---|
| | Corn-After-Soybeans | Corn-After-Corn | Soybeans | Corn-After-Soybeans | Corn-After-Corn | Soybeans |
| Yield (bu./acre) | 174 | 160 | 35 | 190 | 180 | 56 |
| Effective price[1] | $2.45 | $2.45 | $7.49 | $2.36 | $2.36 | $5.91 |
| Crop and LDP revenue[2] | $426 | $392 | $262 | $448 | $425 | $331 |
| Variable costs[3] | 180 | 188 | 109 | 193 | 201 | 112 |
| Crop revenue less v.c. | $246 | $204 | $153 | $255 | $224 | $219 |
| **Rotation Returns** | | | | | | |
| 1/2 corn–1/2 soybeans[4] | | $200 | | | $237 | |
| 2/3 corn–1/3 soybeans[5] | | $201 | | | $233 | |
| Continuous corn[6] | | $204 | | | $224 | |

| | 2005 Projected | | | 2006 Projected | | |
|---|---|---|---|---|---|---|
| | Corn-After-Soybeans | Corn-After-Corn | Soybeans | Corn-After-Soybeans | Corn-After-Corn | Soybeans |
| Yield (bu./acre) | 154 | 140 | 50 | 170 | 155 | 50 |
| Effective price[1] | $2.35 | $2.35 | $5.60 | $2.20 | $2.20 | $5.60 |
| Crop and LDP revenue[2] | $362 | $329 | $280 | $374 | $341 | $280 |
| Variable costs[3] | 206 | 215 | 118 | 214 | 224 | 121 |
| Crop revenue less v.c. | $156 | $114 | $162 | $160 | $117 | $159 |
| **Rotation Returns** | | | | | | |
| 1/2 corn–1/2 soybeans[4] | | $159 | | | $160 | |
| 2/3 corn–1/3 soybeans[5] | | $144 | | | $145 | |
| Continuous corn[6] | | $114 | | | $117 | |

[1] Price includes price for crop sales and average loan deficiency payment.

[2] Equals yield times effective price.

[3] Variable costs include fertilizer and lime, seed, pesticides, drying and storage, machinery repair, machinery hire, and fuel.

[4] Equals average of corn-after-soybeans and soybeans crop revenue less variable costs.

[5] Equals average of corn-after-soybeans, corn-after-corn, and soybeans crop revenue less variable costs.

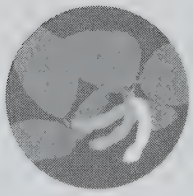
[6] Equals corn-after-corn crop revenue less variable costs.

Source: Farm Business Farm Management, Crop Revenue Less Variable Costs tool on farmdoc (www.farmdoc.uiuc.edu)


Porter, P.M., J.G. Lauer, W.E. Lueschen, J.H. Ford, T.R. Hoverstad, E.S. Oplinger, and R.K. Crookston (1997) Environmental affects the corn and soybean rotation effect. Agronomy Journal 89: 442–448.

Schnitkey, G., and D. Lattz (2005a) Corn returns and soybean returns: do farms differ? Illinois farm economics: facts and opinions. Department of Agricultural and Consumer Economics, University of Illinois. January 11, 2005 (www.farmdoc.uiuc.edu).

Schnitkey, G., and D. Lattz (2005b) Variable cost increases for corn and soybeans in historical perspective. Illinois farm economics: facts and opinions. Department of Agricultural and Consumer Economics, University of Illinois. September 30, 2005 (www.farmdoc.uiuc.edu).



# Have We Wasted Time and Money on Preparedness?

Gary Schnitkey

Considerable sums of money have been spent preparing for an outbreak of Asian soybean rust in the United States. Interest intensified after discovery of rust in the southern United States in 2004. After this discovery, many farmers in the Midwest began preparing for a rust outbreak. Some might suggest that funds and attention spent have been unwarranted because a significant outbreak of rust did not occur in the Midwest in 2005. I do not hold this view and believe that funds and effort spent on rust were, largely, a wise investment. In support of this stand, I offer the following five perspectives.

## 1. Not having a significant rust outbreak in 2006 provides little information

Many models of soybean rust suggest that an outbreak would not occur every year. For example, the Economic Reporting Service (ERS) of the U.S. Department of Agriculture reported on results from an infection model run to predict the incidence of soybean rust in various regions of the United States (Livingston et al. 2004). The results suggest that soybean rust outbreaks will occur in Illinois between 71 and 80% of the years once rust becomes endemic to the southern United States. For simplicity, let's say that outbreaks occur 75% of the time, or 3 out of 4 yr.

In 2005, an outbreak did not occur. This could simply mean that 2005 was in the 1 out of 4 yr in which an infestation will not occur. Some support of this reasoning comes from weather conditions in 2005. Generally, rust has less chance of spreading in dry years, as in 2005. Hence, 2005 is a likely year in which rust would not occur.

More information will come in 2006. If a rust outbreak does not occur in 2006, then it is much more likely that models predicting high occurrences of rust are wrong. If the prediction that soybean rust will occur 75% of the time is correct, then there is only a 12.5% probability that rust will not occur in two successive years.

In reality, it will take many years to know with precision how often soybean rust will be a problem. Currently, we know that soybean rust will not be a problem in the Midwest every year.

## 2. Soybean is of high value in the United States and Illinois

The value of soybean production in 2004 was $16.1 billion, representing 21% of the total value of field crop production in the United States (National Agricultural Statistical Service 2005b). Soybean ranks as the second largest crop in the United States, with corn as the only crop with higher value of production. There were 72.4 million acres planted to soybean in 2004, representing 22% of the acres in principal crops in the United States (National Agricultural Statistical Service 2005a).

Illinois farmers harvested 10.2 million acres of soybean, representing 43% of acres harvested in Illinois (National Agricultural Statistical Service 2005a). The value of production of soybean in Illinois was $2.5 billion in 2004 (National Agricultural Statistical Service 2005b). In terms of crop production, soybean acres and value rank second only to corn.

The above-mentioned statistics point out the importance of soybean as a crop both in the United States and in Illinois. This importance suggests that funds

can be spent by the public sector on a pest that will affect soybean.

## 3. Soybean rust could be a costly problem

A study published by the ERS indicated that the costs in the first year of soybean rust outbreak could range between $640 million up to $1,341 million, depending on the severity of the outbreak. This same study indicated that costs in the medium run could range between $240 million up to $2,004 million (Livingston et al. 2004). In the medium run, about 70% of the costs are born by soybean producers; however, other groups lose, including livestock producers (5% of the loss) and consumers (25%). The only group that gains from a rust outbreak is "other crop producers."

Individual producers have the possibility of losing from a rust outbreak. For severe outbreaks, estimates suggest it is possible to lose more than 10% of yield if rust occurs. Moreover, fungicide costs could be substantial. For simplicity, let's suppose that rust could cause loses of $10 per acre of soybean, a relatively conservative estimate. Costs on a 1,500-acre farm with 750 acres under this scenario would be $7,500 for this farm.

The potential costs, along with the importance of the crop, suggest that considerable funds could be spent from a public perspective on combating soybean rust. For farmers, outbreaks are costly enough to warrant attention. In the 2005 planning season, some farmers may have incurred out of pocket costs for sprayers, and, perhaps, stockpiling some fungicide. Thus far, however, most of the costs spent by farmers come in the form of learning about the fungus and its control measures. It is difficult to place a value on learning costs; however, in my opinion, it is not likely that many farmers have passed the threshold of spending too much effort learning about soybean rust.

## 4. Not being prepared could be viewed as problematic

The possibilities of Asian soybean rust being a problem have been known for several years. Brazil has had difficulties with the fungus and has suffered economic losses. The outbreak in southern United States gave the United States several months to prepare for the possibility of rust.

Given the warnings concerning rust, not undertaking preventive and training measures would be unwise. Setting up systems for monitoring for soybean rust, developing effective measures for combating rust, and learning more about the disease seem like prudent measures. If these measures had not been undertaken and rust had occurred, serious questions would have been asked of individuals within the soybean industry about their ability to react and handle the challenges of the soybean industry.

Moreover, not reacting to a serious pest problem would place soybean at a disadvantage relative to other crops. If soybean loses profit-generating potential because of rust, other crops likely would gain in acreage at the expense of soybean. Hence, not reacting to the rust challenge could place the soybean industry at a disadvantage.

## 5. Rust not occurring in 2005 may cause underestimation of rust

Humans have difficulty judging the possibility of adverse events. Typically, people put a higher probability on an adverse event when it has recently happened, whereas they place a lower probability on an event if it has not happened recently. Individuals within the Illinois soybean industry may underestimate the risks associated with soybean rust because it did not occur in Illinois during 2005. Hence, thoughts that costs associated with proactive measure were imprudent may be increased beyond what they should be because rust did not occur in 2005.

## Summary

An introduction of soybean rust could have serious impacts on the soybean producing sector as well as negative impacts on livestock producers and consumers. Given the potential large impacts, and the importance of soybean, efforts spent on Asian soybean rust are warranted.

Even if soybean rust does not become a serious problem, efforts and funds spent dealing with rust likely will be warranted. Preparing for adverse events should not be judged as undeserved efforts if the event does not occur. Ex post evaluations are always easier than ex ante evaluations or, in other words, hindsight is 20-20. Prudent risk management involves planning for adverse events than may not happen rather than simply hoping that the event does not occur.

## References

Livingston, M., R. Johansson, S. Daberkow, M. Roberts, M. Ash, and V. Breneman

(2004) Economic and policy implications of wind-borne entry of Asian soybean rust in the United States. Economic Reporting Service, U.S. Department of Agriculture. OCS-04D-02.

National Agricultural Statistical Service, U.S. Department of Agriculture (2005a)

Acreage (http://www.usda.gov/nass/pubs/reportname.htm#Acreage).

National Agricultural Statistical Service, U.S. Department of Agriculture (2005b)

Crop values: 2004 summary. Pr 2(05)b.

# Illinois Soybean Rust Summary: "Dust Off Your Rust Plan"

Suzanne Bissonnette

Asian soybean rust will be a continuing threat to soybean production in the United States in the upcoming 2006 growing season. This significant disease first was identified in the United States in November 2004. Before continental introduction, a state taskforce was initiated in Illinois to prepare the state for the possible introduction of soybean rust to Illinois. The taskforce dealt with numerous issues, including protocols such as monitoring, scouting, sampling, and identification; educational issues such as training and rust education for first responders, field scouts, producers, and agribusiness personnel; plant sampling and diagnosis issues such as expansion of online sample screening for soybean rust and designation of University of Illinois Plant Clinic as state triage site for Illinois; regulatory issues such as granting of section 18s and preparedness of licensed applicators in the state; research efforts; and multiple media issues. The State Soybean Rust Taskforce Plan can be found at http://www.agr.state.il.us/; it has been updated as the disease has progressed. The taskforce continues to address educational, regulatory and diagnostic issues relevant to the soybean rust in Illinois.

During the 2005 growing season, starting from mid-Florida, rust slowly made its way northward throughout Florida to Alabama, Georgia, Mississippi, and South Carolina. Considerable effort was put into the monitoring of the spread of soybean rust this past season. Soybean-producing states each had sentinel field plots that were scouted weekly for the presence of rust. The sentinel program has three functions. First, to quantify the timing of soybean rust spore production in overwintering and growing season source areas (see http://www.ces.ncsu.edu/depts/pp/soybeanrust/index.php ); second, to serve as a warning network for new disease observations in the soybean production regions; and third, to provide a means to collect data for epidemiological research. Results of monitoring are input on the official USDA Soybean Rust Web site at http://www.sbrusa.net/. Throughout the growing season, check this site daily because national and local maps and individual state commentary are regularly updated. Numerous first detections were observed in the sentinel plots. The USDA will again sponsor the sentinel plot program so it will continue for the 2006 growing season.

Illinois had 40 sentinel plots in 2005 located across the state (Figure 1). Sentinel plots were funded by the USDA, the United Soybean Board, and the North Central Soybean Research Program (NCSRP). One standard protocol was developed and used for both NCSRP and USDA plots. Sentinel plots were planted with varieties adapted for their location; maturities could be a mix of early and late varieties. If multiple varieties were planted, it was recommended that each variety have four rows with no spacing between varieties. Plot size was designated as 50 × 50 foot or larger with a center area of 30 × 30 foot for scouting. Scouting protocol called for scouting at a weekly interval before predicted spore arrival and scouting at 3- to 4-day intervals after predicted spore arrival or soybean rust is reported in a neighboring state. Then, scouting would return to a weekly interval after first confirmed observation in plot. Observations required and recorded were global positioning system (GPS) location, cultivar description/name, planting date, row spacing, planting density, and field acreage. During each observation date, plant height, degree of canopy closure, and the vegetative and reproductive growth stages are recorded. Disease

**Figure 1. 2005 Illinois sentinel plot map.**

severity was assessed using the following categories: absent, low, medium, and high.

In Illinois sentinel plots, numerous invaluable cooperators scouted throughout the 2005 season. The program will be continued in the 2006 season (Table 1). The National Soybean Research Lab maintains a Web site with soybean rust information and as a hub for in-state sentinel plot data reporting for sentinel scouts at http://www.soybeanrust.org/. These data are uploaded to the national USDA Web site http://www.sbrusa.net/.

In Illinois (2004), University of Illinois Extension designated a specialized section of our University of Illinois Digital Distance Diagnostics Imaging (DDDI) system to aid in early detection of Asian soybean rust. The online service available at all county extension unit offices was further upgraded in 2005. This system is essentially an online plant clinic and with regard to soybean rust, our goal is prescreening and early detection of rust-infected plants. Samples can be submitted to

**Table 1. 2005 Illinois sentinel plot scout and locations**

| Illinois County | Location | Scout/affiliation |
|---|---|---|
| Adams | Ursa | Mike Roegge UIUC |
| Alexander | Tamms | Chris Vick SIU |
| Champaign | Urbana | Tara Lynch UIUC |
| Champaign | Urbana (pea) | Tara Lynch UIUC |
| Clinton | Breese | Dennis Epplin UIUC |
| DeKalb | DeKalb | Lyle Paul UIUC |
| Edgar | Paris | Tara Lynch UIUC |
| Fayette | Brownstown | Tara Lynch UIUC |
| Ford | Gibson City | Tara Lynch UIUC |
| Gallatin | New Haven | Jason Bond SIU |
| Grundy | Dwight | Tara Lynch UIUC |
| Jackson | Carbondale | Jason Bond SIU |
| Jersey | Jerseyville | Robert Bellm UIUC |
| Lee | Ohio | Jim Morrison UIUC |
| Livingston | Pontiac | Tara Lynch UIUC |
| Madison | St. Jacob | Robert Bellm UIUC |
| Marion | Salem | Dennis Epplin UIUC |
| Massac | New Columbia-Mermet | Ron Hines UIUC |
| Massac | Off-station (kudzu) | Ron Hines UIUC |
| McLean | Bloomington | Tara Lynch UIUC |
| Monroe | Valmeyer | Ron Krausz SIU |
| Montgomery | Hillsboro | Kelli Bassett UIUC |
| Moultrie | Sullivan | Tara Lynch UIUC |
| Ogle | Mt Morris | Bill Lindenmeyer UIUC |
| Pike | Perry | Mike Roegge UIUC |
| Pope | Dixon Springs | Ron Hines UIUC |
| Pulaski | near Ullin | Ron Hines UIUC |
| Pulaski | Ullin | Jason Bond SIU |
| Richland | | Tara Lynch UIUC |
| Saline | Harrisburg | Jason Bond SIU |
| Sangamon | New Berlin | Matt Montgomery UIUC |
| Shelby | Moweaqua | Tara Lynch UIUC |
| St. Claire | Belleville | Ron Krausz SIU |
| Tazwell | Minier | Tara Lynch UIUC |
| Warren | Monmouth | Eric Adee UIUC |
| Washington | Nashville | Terry Wyciskalla UIUC |
| White | Carmi (vegetable bean) | Jason Bond SIU |
| Whiteside | Erie | David Feltes UIUC |
| Will | Joliet | Tara Lynch UIUC |
| Woodford | Goodfield | Tara Lynch UIUC |

the University of Illinois' DDDI system at your county extension unit office (Figure 2). The results of soybean rust prescreening via DDDI are available within a few hours. If the DDDI prescreening seems suspect, a plant sample is submitted via overnight mail to the University of Illinois Plant Clinic. A fee is charged to clientele for any mailing costs before detection in the state.

Unprecedented face-to-face educational efforts for a single disease were put forth in 2005 for soybean rust education. Training opportunities by extension were offered in the areas of first responder training, in-depth soybean scouting clinics, distance digital diagnostics, fungicide short courses, aerial application fly–in, regulatory issues, applicator licensing, diagnosis training, and update seminars.

Printed and online educational materials developed included a news release series at http://www.ipm.uiuc.edu/fieldcrops/soybeans/diseases.html; in season articles in the Bulletin at http://www.ipm.uiuc.edu/bulletin/index.php; fungicide spray




**Figure 2. University of Illinois Extension Distance Diagnostics Locations.**

**Table 2. Illinois Asian Soybean Rust Fungicide Information**

**EPA SOYBEAN RUST SECTION 3 FUNGICIDES**

| Common name | Fungicide trade name | Manufacturer | Rate/acre | Application (GPA) | Labeled no. Applications | PHI (days) | Chemical class | Mode of action |
|---|---|---|---|---|---|---|---|---|
| Azoxystrobin | Quadris | Syngenta | 6.2–15.4 fl oz | Adequate coverage & penetration, include crop oil | 1–2 | 14 | Strobilurin | Protectant |
| Chlorothalonil | Bravo Weather Stik, | Syngenta | 16–36 fl oz | 20–150 5–10 air | 1–3 | 42 | Benzonitriles | Protectant |
| | Echo 720 | Sipcam Agro | 16–40 fl oz | 20–150 5–10 air | 1–3 | 42 | | |
| | Echo 90DF | Sipcam Agro | 14–32 oz | 20–150 5–10 air | 1–3 | 42 | | |
| | EQUUS 720 SST | Farmsaver.com | 1.37–2.25 lbs | | 3 | 42 | | |
| | EQUUS DF | Farmsaver.com | 1.25–2.2 lb | 10–20 | 3 | 42 | | |
| Pyraclostrobin | Headline | BASF | 6–12 fl oz | Thorough coverage of foliage | 1–2 | 21 | Strobilurin | Protectant |

**EPA SOYBEAN RUST SECTION 18 FUNGICIDES (SECTION 18'S IN EFFECT UNTIL 11/10/2007)**

| Common name | Fungicide trade name | Manufacturer | Rate/acre | Application (GPA) | Labeled no. Applications | PHI (days) | Chemical class | Mode of action |
|---|---|---|---|---|---|---|---|---|
| Myclobutanil | Laredo EC | Dow AgroSciences | 4–8 fl oz | Adequate coverage & penetration | 1–2 | 28 | Triazole | Curative |
| | Laredo EW | | 4.8–9.6 fl oz | 15–20<br>5 air | 2 | 28 | | |
| Propiconizole | Tilt | Syngenta | 4–8 fl oz | 15<br>5 air | 1–2 | 28 | Triazole | Curative |
| | Bumper 41.8EC | Makhteshim-Agan | 4–8 fl oz | 15<br>5 air | 1–-2 | 28 | | |
| | Propimax EC | Dow AgroSciences | 4–8 fl oz | 15<br>5 air | 1–2 | 28 | | |
| Tebuconazole | Folicur 3.6F | Bayer | 3–4 fl oz | 10<br>5 air | 1–2 | 21 | Triazole | Curative |
| | Orius 3.6F no label IL | Makhteshim-Agan | 3–4 fl oz | 10<br>5 air | 1–2 | 30 | | |
| Tetraconazole (unregistered) | Domark 230ME | Valent | 10–13 fl oz | 20–150<br>5–10 air | 1 | 21 | Triazole | Curative |
| Trifloxystrobin + Propiconizole | Stratego | Bayer | 5.5–10 fl oz | 10<br>5 air | 1 | 21 | Triazole + Strobilurin | Curative + Protectant |
| Propiconizole + Azoxystrobin | Quilt | Syngenta | 6.2–12 oz | (apply w/ 0.5% COC) | 1–2 | 21 | Triazole + Strobilurin | Curative + Protectant |
| Pyraclostrobin + Tebuconazole | Headline SBR | BASF & Bayer | 7.8 fl oz | Thorough coverage<br>5 air | | 30 | Triazole + Strobilurin | Curative + Protectant |

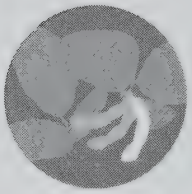
Fungicide information as of 09/19/2005; please check the Environmental Protection Agency Web site for most current Section 3 and Section 18 registrations and listing of allowed states. http://www.epa.gov/oppfead1/cb/csb_page/updates/soybean_rust.htm#section3

recommendations fact sheet; NC IPM soybean rust fact sheets at http://www.aphis.usda.gov/lpa/issues/sbr/Soybean_Rust_22.pdf; and an NCR 504 scouting brochure at http://www.aphis.usda.gov/lpa/issues/sbr/SBR_IDcard_11-04.pdf. University of Illinois Extension printed resources for soybean rust can be ordered online at www.PublicationsPlus.uiuc.edu or by calling 800-345-6087. First, all soybean producers and scouts should have a Field Crop Scouting Guide (X880d Field Crop Scouting Manual) and the reprinted and updated soybean disease pocket guide (C1380 Pocket Guide to Soybean Diseases). Also, new and specifically for soybean rust a disease assessment tool (X881 Soybean Rust Assessment Tool) as well as a hand lens for soybean rust scouting endeavors (X882, Folding Pocket Magnifier, 20X). Also, a new Extension Report on Plant Disease #1002 "Characteristics of Fungicides for Field Crops" at http://www.ag.uiuc.edu/~vista/abstracts/a1002.html is an excellent resource for you when making fungicide decisions.

Continuation of in-depth face-to-face training for competent sampling, scouting, identification, and reporting and management of soybean rust by clientele continues this season. Many educational seminar opportunities will be available this winter with the latest Soybean Rust information as it relates to Illinois soybean production. Numerous Corn & Soybean Classics and Regional Extension Crop Management conferences as well as local Extension Agronomy Day winter meetings at http://web.extension.uiuc.edu/cie2/offices/calendar.cfm will be in your area for Asian soybean rust updates and training.

Additionally, University of Illinois Extension maintains a web site with specific soybean rust information for Illinois at http://soyrust.cropsci.uiuc.edu/index.cfm. Information about the disease, current fungicide information, state soybean rust taskforce information, and information on scouting and sample submission for the disease can be found on this site.

Fungicide selection, application, and regulatory issues will continue to be issues as soybean rust progresses. As of September 2005, our current recommended fungicides for the management of soybean rust are listed in Table 2. Continuation of in-depth training for competent and legal selection and application of fungicides for the management of soybean rust by clientele will continue to be a key component of our educational effort to manage soybean rust in Illinois.



# Perspectives from Alabama: What Did We Learn?

Edward J. Sikora, Arcenio Gutierrez-estrada, Dennis Delaney, Jacqueline Mullen and James Jacobi

## Distribution of Asian Soybean Rust in Alabama in 2004

Asian soybean rust, caused by the fungus *Phakopsora pachyrhizi*, was first detected in the continental United States in Louisiana in early November, 2004. Over the next few weeks, the disease was detected in eight other southeastern states. Most likely, spores of the pathogen were carried by winds of Hurricane Ivan into the region. In Alabama, soybean rust was first confirmed on soybean leaves collected from Mobile County in mid-November. A follow-up survey found the disease on soybean in 18 of Alabama's 67 counties, and as far north as the Tennessee border. Detection of soybean rust in Alabama occurred after most soybean in the state had been harvested. As a result, the impact of the disease on the 2004 soybean crop was minimal.

## Soybean Rust Activities Conducted by Auburn University, 2005

In preparation for an outbreak of soybean rust in 2005, grower education was made a priority in the winter before the growing season. Soybean acreage in Alabama in 2004 was estimated at 210,000 acres, which is probably less than what is grown in most individual counties in Illinois. Most growers in our state consider soybean a secondary row crop after cotton, peanuts, and corn. However, soybean growers were aware of the potential problems associated with the disease and came out in relatively large numbers to attend soybean rust programs presented by the Alabama Cooperative Extension System. In all, 17 soybean programs were conducted in winter 2005 with more than 500 growers in attendance. Growers were given a general update on soybean rust history, identification, biology, and management. Other soybean rust-related activities conducted by Auburn University included the following:

- Direct mailings of soybean rust information to Alabama soybean growers
- Developing the Auburn University Soybean Rust Web site http://www.aces.edu/dept/soybean/soybean_rust/
- Participating in USDA soybean rust monitoring program
- Established soybean and kudzu sentinel plots
- Providing updates on the USDA Public Soybean Rust Web site www.sbrusa.net
- Maintaining Syngenta spore traps
- Maintaining the Auburn University Soybean Rust Hotline 1-800-774-2847
- Conducting 10 fungicide trials on soybean, cowpea, and lima bean

## Alabama Soybean Rust Sentinel Plot Network

The sentinel plot system was established with support from the North Central Soybean Research Program and USDA–APHIS. The plots were used for early detection of the disease and for measuring disease progress over time. Twenty-five soybean sentinel pots were established around the state. In addition, 15 kudzu patches were identified for weekly monitoring for the disease. A soybean sentinel plot was a 50 × 50-ft plot of soybean planted approximately 2 wk before the normal time of planting for an area. Sentinel plots were scouted weekly beginning at the first-true leaf stage.

Leaves from suspect plants were collected and taken to the Auburn University Plant Diagnostic Laboratory located at Auburn or Birmingham for disease confirmation. Four plots were designated as "epidemiological" plots, and these plots were used for more intensive epidemiological observations. Information obtained from the sentinel plot system was used to support the USDA National Soybean Rust Sentinel and Monitoring Network.

## Soybean Rust in Alabama, 2005

The soybean rust fungus, which requires living tissue to survive, did not overwinter in Alabama. The disease was detected on kudzu in Florida in March, indicating that the pathogen survived the winter in the United States. The first report of soybean rust in Alabama in 2005 was in a soybean sentinel plot located at the Gulf Coast Research and Extension Center in Fairhope. The station is in Baldwin County on the east side of Mobile Bay in the southwestern corner of the state. The disease also was found in a 50-acre commercial soybean field in the immediate area at about the same time. Fortunately, the grower applied a fungicide shortly after the time when initial disease development was suspected, but before detection. Two aerial applications of the fungicide Stratego® applied 21 d apart seemed to control the disease. The same grower had a 1-acre field directly across the road from the 50-acre field described above. This field was not sprayed with a fungicide, and severe defoliation from soybean rust was observed as the season progressed. Other growers in the area alerted to the presence of rust initiated a fungicide spray program shortly after the initial finding of rust in the sentinel plot. This action apparently reduced any significant damage from the disease.

In general, the disease did not seem to spread through the state as we had anticipated. Fears that the disease would move 100 miles in a day were reduced when field observations suggested that field to field spread was limited, although spread within a field could be very rapid. Why this occurred could be due to low initial inoculum levels; unfavorable weather conditions, because Alabama experienced a relatively hot, dry period from July through September (with the exception of the occasional hurricane); or a combination. The best example of the low level of field-to-field spread was observed at the E. V. Smith Research Center near Montgomery, AL. Soybean rust was observed in a soybean sentinel plot on the station on 3 August. The disease progressed fairly quickly through the plot over the next few weeks. However, the disease was not detected until late August in multiple unsprayed soybean trials within 500 yards from the sentinel plot. Why the disease did not spread more quickly is unclear.

As of 17 October, soybean rust was detected in 16 Alabama counties. This number included 12 commercial soybean fields, 10 soybean sentinel plots, and four kudzu patches. The disease was most frequently found in commercial fields in southern one-third of the state. There were no reports of significant yield loss in the commercial fields where the disease was observed.

## Fungicide Spray Programs

Before 2005, soybean growers in Alabama were not accustomed to spraying their crop with fungicides. We estimate that more than 95% of the growers did not use fungicides before 2005. In 2005, we estimate that 50% or more of the soybean growers in Alabama made at least one fungicide application. The combination of the threat of rust and the knowledge that one well-timed fungicide application at the R2–R3 growth stage could significantly reduce yield loss from other foliar diseases such as frogeye leaf spot and Cercospora blight, apparently induced a number of growers to take on the added expense of a fungicide application. In general, frogeye leaf spot was a significant problem in Alabama in 2005, and a well-timed fungicide application would likely have paid for itself this year.

## What We Learned in 2005

Soybean rust did overwinter in the United States and will be a factor in soybean production in this country for years to come. The disease did not spread as rapidly as expected, but this response may have been due to low inoculum levels this first year. We suspect the disease will become more widespread and damaging in 2006 and thereafter, especially now that it apparently has a foothold in Florida. Fungicide applications did prevent the disease from causing significant damage in Alabama in 2005. Preventative fungicide applications would be the most effective method of control. However, curative applications shortly after the disease is introduced into a field could be effective if the disease levels are relatively low, which was observed in the commercial field in Baldwin County in 2005.

Growers in the southeastern United States are more at the mercy of the Asian soybean rust than their fellow soybean growers in the Midwest. The disease will likely overwinter at our doorstep in Florida each year, and unfortunately we have no built-in geographical early warning system to alert us to an approaching epidemic.

Growers in Illinois need to be aware of the development and spread of soybean rust in the southeastern United States each year. This information should be made available through their state extension system. This knowledge along with the possibility of one well-timed fungicide application may be all that is needed to keep soybean rust in-check in Illinois.

# Fungicides: What They Do and How They Work

MARTIN A. DRAPER

Management of soybean rust is dependent on early detection. After identifying the disease, the greatest successes have resulted from early response with an efficacious fungicide applied properly. The activity of the fungicide along with the product's residual and coverage determines the period of protection from any disease. Soybean rust can be particularly troublesome because of the many infection sites that can occur, making protection across the leaf and throughout the canopy critical for superior disease control. There are three general strategies for use of the three classes of fungicides available for control of soybean rust.

True protectants reside on the outside of the plant and have limited diffusion across the leaf surface from the point of droplet deposition. This class of fungicides includes the chloronitrile group of fungicides, represented by the active ingredient chlorothalonil. Chlorothalonil is sold under several brand names, including Bravo, Echo, and Equus. This chemistry is essentially generic in that the U.S. patent rights have expired for the developer, so more product trade names may emerge over time as other registrants apply to the Environmental Protection Agency (EPA) for use of the chemistry. Other true protectants may have activity against soybean rust, but they are not currently labeled in the United States and Canada. These products must be applied before infection in a *protectant preventative* use strategy.

The two remaining fungicide classes used for soybean rust are the triazoles and the strobilurins. There are a wide range of products with in these classes, but fundamentally a triazole is a triazole and a strobilurin is a strobilurin. Each product within the triazole class has the same mode of action as other triazoles, and each strobilurin fungicide has the same mode of action as other strobilurins. One similarity is that both the triazoles and strobilurins are systemic products, moving into and through the leaf, or to a varying extent moving with the water flow. As such, a droplet that lands on a leaf diffuses into the leaf and as it enters xylem cells, it may move to the leaf margins, up and out.

The timing of these applications of systemic products determines whether the use strategy is as a *systemic preventative* or *systemic curative* approach. Application before infection is preventative, and postinfection is a curative or antisporulant strategy. Preventative applications are most efficacious. Curative strategies become less efficacious the later they are applied after infection. Only triazoles should be used in a curative or antisporulant strategy. Stroblurins pose a greater risk of resistance in the pathogen population. When they become resistant, the shift is qualitative within that isolate of the pathogen population, which means they stop working completely. Whenever a product is applied postinfection, the resistance risk is increased.

Triazole fungicides include propiconazole (Tilt, PropiMax, and Bumper), tebuconazole (Folicur, Uppercut, Falcon, and others), tetraconazole (Domark), and myclobutanil (Laredo). Other triazoles may enter the market in the coming months. Strobilurin fungicides include azoxystrobin (Quadris), pyraclostrobin (Headline), and trifloxystrobin. Each of these fungicides is available in premix formulations with a triazole, with Quadris and Headline being solo formulations of the strobilurin.

Managing resistance risk also can be addressed by using premixes and tank mixes of multiple modes of action. Generally, this mix is with a triazole. Trifloxystrobin

noted above is sold in a tank mix with propiconazole as Stratego. Other premixes and copacks include Quilt (azoxystrobin + propiconazole) and Headline SBR (pyraclostrobin + tebuconazole). Other premixes will be entering the market soon and should all be used as preventative treatments.

In *all* cases, when a producer or a commercial applicator treats a crop with a fungicide, he or she must understand the mode of action of that pesticide and have a realistic expectation of what that treatment will do. The fungicides that are on the market are very good when used properly to treat disease in the face of disease risk. However, there are no silver bullets that will cure all diseases, under all situations, and under all conditions.

# Optimizing Soybean Yields for Tomorrow with Today's Technologies

JEFF BUNTING

Soybean production in the United States has changed considerably over the past 10 years. As one of the top soybean-producing states, Illinois has been in the forefront of these changes. Technological advances in seed, herbicides, fungicides, and insecticides have created opportunities for producers to grow soybean more efficiently and economically. However, even with these advances, soybean commodity prices have remained stable, and for many producers, so have soybean yields. Stagnant soybean yields and the threat of devastating diseases, such as Asian soybean rust, jeopardize future soybean production. These issues aside, Illinois soybean production is higher today than it was in 1995 (Figure 1). Reasons for the growth in soybean acres are the yield and economic advantages in a corn and soybean rotation. However, with record-high prices for natural gas and nitrogen, one must ask, "Will producers abandon this rotation and grow more soybean? What will happen to soybean yields?"

## Current Changes in Soybean Production

Over the past 10 years, one of the biggest changes in soybean production has been the introduction of Roundup Ready soybean for weed control. Currently, more than 80% of Illinois soybean acreage is planted to Roundup Ready soybean. This change alone has helped increase no-tillage acres, reduce yield losses due to weed competition, and increase the efficiency of weed management in soybean. However, even with the positive attributes that this technology has brought, there continue to be weed management issues in soybean. For example, because glyphosate has a larger application window for weed control, growers are trying to get away with just one application of glyphosate. With only one application, growers often sacrifice yield due to early or late-season competition, or a combination, from weeds with extended germination periods, such as waterhemp and giant ragweed. Additionally, within the past 10 years, there have been numerous formulations of glyphosate. Because not all of these glyphosate products are created equal, there is a lot of confusion among growers about what rates and additives should be used to achieve maximum weed control, particularly with rebates and other incentives driving the market. Another concern in the current system is the potential population shift to glyphosate-resistant weeds, and weeds that are finding niches in a glyphosate-only system.

Soybean diseases also have gained more prominence over the past several years. The occurrence of diseases such as sudden death syndrome (SDS), rhizoctonia, and other seedling diseases has increased. One of the biggest changes that may have contributed to the rise of some of these diseases is the increased production of no-tillage soybean. Currently, more than 45% of the soybean acres in Illinois are grown without tillage (Figure 2). Because of these changes, the use of seed treatments and foliar-applied fungicides to protect soybean from diseases has increased. Additionally, it is currently assumed that these products also may improve general plant health. The verdict is still out on whether such benefits are real, but research to optimize the use of seed treatments and foliar-applied fungicides is being conducted. Soybean cyst nematode (SCN) also has increased tremendously in Illinois over the past 10 years. Integrated approaches and the development of resistant soybean varieties have helped keep this pest under control.

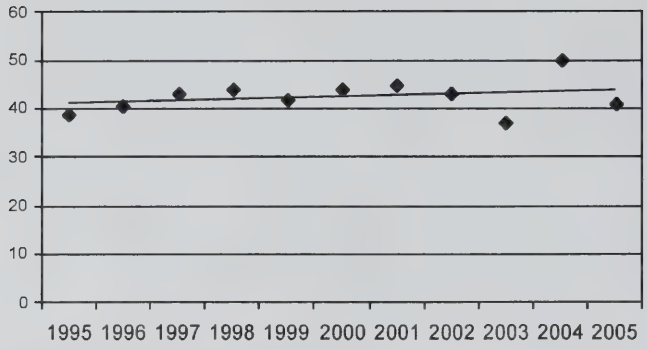



**Figure 1. Illinois soybean yields from 1995 to 2005.** The yield in 2005 is the forecast based on the August crop report. Source: National Agricultural Statistics Service.

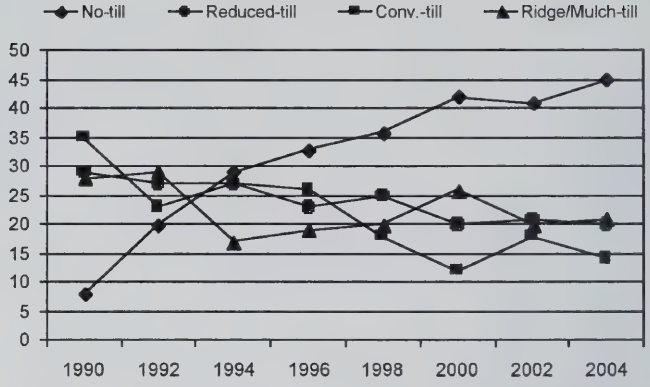



**Figure 2. Illinois tillage trends for soybeans since 1990 to 2004.** Source: Conservation Technology Information Center.

Ten years ago, if someone would have told you that you would be applying insecticides regularly in soybean, you probably wouldn't have believed them. Unfortunately, as soybean production has increased over time, so have insect pests. Soybean aphid and spider mites have gained more prominence and have proved that they can cause significant yield losses. Currently, insecticides are used to help manage these pests, adding to the overall cost of soybean production. Efforts are being made to help identify sustainable management strategies for these pests. Because the Illinois soybean producer has more pests to deal with than he or she did 10 years ago, the producer also has many more options for controlling these pests. It is going to be important to move forward with research to help address these concerns and to bring the overall costs of soybean production down, while increasing soybean yields for a sustainable future.

## Future Changes in Soybean Production

Although Illinois producers have had to deal with their fair share of soybean pests, Asian soybean rust is another potential problem in the years to come. There are several efforts being made to help with identification and management strategies to help keep this devastating soybean disease under control.

Despite the current and potential pest control issues, the future of biodiesel and specialty soybean products looks extremely bright. Biodiesel consumption in the United States continues to increase, with more than 30 million gallons consumed in 2004 (National Biodiesel Board 2005). Competition continues to come from foreign countries, but the United States continues to supply the markets with high-quality soybean. To stay competitive in this global market, we will need to address the current pest management issues. It will be important to identify the yield-limiting factors in a field, county, and across the state to remain competitive in a global market. Health benefits of soybean will start being promoted as this conference kicks off the 2006 calendar year. The Food and Drug Administration will require labeling of all *trans* fatty acids at the beginning of the year, which bodes well for foods with soybean. Food labels, including those for certain dietary supplements, must include *trans* fat in nutrition labeling on products being introduced into interstate commerce. Variable costs have increased significantly in the past 10 years (Illinois Farm Business Farm Management 2005). Illinois producers are paying twice as much for seed, fertilizer costs have increased 15%, and pesticide costs have decreased by only 10%. These changes will have a negative impact on profitability. As profitability decreases, crop production management must align with crop protection issues to result in effective means to control soybean pests while maintaining profitability and integrated pest management practices. In 2015, soybean production will continue to increase, commodity prices will be higher, and Illinois football will once again be in a postseason bowl game. Well, two out of three won't be bad.

## References

Illinois Farm Business Farm Management. 2005. Available at www.farmdoc.uiuc.edu. Accessed October 2005.

National Biodiesel Board. 2005. Available at www.biodiesel.org. Accessed October 2005.

Soy Stats. 2004. Available at www.soystats.com. Accessed October 2005.

# Twospotted Spider Mites: Case Study in Soybean Pest Management

Kevin Steffey, Mike Gray, Ron Estes, Jared Schroeder, Darren Bakken, Dan Schaefer, and Gordon Roskamp

Spider mites are an annual threat to corn and soybean production in the drier regions of the Midwest (e.g., Kansas, Nebraska). However, in Illinois, the twospotted spider mite (*Tetranychus urticae*) threatens soybean production usually during periods of hot, dry weather, especially when these conditions persist. Over the past 25 years in Illinois, widespread outbreaks of spider mites in soybean have occurred in 1983, 1988, and 2005. In other years when drought conditions were regional within the state, outbreaks of twospotted spider mites have been localized.

In 1983, entomologists and county Extension advisers in Illinois estimated that ~2.2 million acres of soybean was treated for control of twospotted spider mites (Colwell 1984). The acreage of soybean treated for control of insects (including bean leaf beetle and woollybear caterpillars) and mite in 1983 was the largest that had ever been reported in Illinois at that time. In 1988, the year of the most severe drought in Illinois in recent history, ~3.5 million acres of soybean was treated for control of twospotted spider mites (Pike et al. 1990). During that same year, >450,000 acres of soybean was sprayed for control of bean leaf beetles (Pike et al. 1990).

When drought conditions persisted in Illinois during June and July 2005, infestations of twospotted spider mites were not unexpected. Many soybean fields were treated during the summer for control of spider mites, and some fields were treated more than once. Unfortunately, a formal estimate of the acres of soybean treated for spider mite control in Illinois in 2005 is not available. Our best guess is that more than 1 million acres of soybean was sprayed for control of twospotted spider mites in Illinois in 2005. Additional acres were sprayed for control of soybean aphids. Some soybean fields were treated for control of both pests. We suspect that between 2 and 3 million acres of soybean in Illinois was treated with insecticides in 2005. Infestations of twospotted spider mites also developed in other Midwestern states (e.g., Iowa, Wisconsin) in 2005.

Because infestations of twospotted spider mites occur sporadically in Illinois, we do not have a database from which we regularly can extract information regarding the best way to manage these pests. Consequently, we must review the scientific literature and popular agricultural press articles every time spider mites threaten soybean production. Some of the information remains relevant over time, and we can add new findings as they are obtained. This report focuses on what we knew about twospotted spider mites before 2005, what we learned during 2005, and what we can suggest as management strategies for the future.

## Twospotted Spider Mites—Then

***Biology of twospotted spider mites.*** A brief overview of the biology of twospotted spider mites is appropriate. More details about spider mites in soybean have been written by Klubertanz (1994).

In northern states, twospotted spider mites overwinter as adult females in sheltered areas such as field margins. In the spring, the females typically crawl from the plants on which they overwintered to other plants such as soybean. The females lay very small, spherical, pearly white eggs on the plants, and six-legged larvae hatch within a few days. The immature stages include the six-legged larvae, eight-legged protonymph, and eight-legged deutonymph. Eight-legged adults are 0.3 to 0.4 mm long, depending on the sex (females are

robust, males are slender), and green-yellow to dull orange. The adults have food balls that concentrate in two spots on either side of the abdomen; hence, the common name twospotted spider mite. Adult females produce as many as 300 offspring in the first month of egg laying.

The life cycle of twospotted spider mites is completed in 4 to 14 days, depending upon the temperature. Fastest development occurs at temperatures above 91°F. When temperatures are high and moisture is lacking, twospotted spider mite populations in soybean undergo exponential growth. Numerous generations are completed within a single growing season.

As densities of twospotted spider mites increase, the mites spread through a field of soybean by crawling from plant to plant or by "ballooning." When densities of spider mites on a plant become very large, female mites often congregate at the tips of leaflets and spin webs. The wind catches the webbing and bears the mites aloft, moving the mites to other areas within a field or to other fields.

There are two natural enemies of twospotted spider mites that may help regulate spider mite populations—predaceous mites and a fungal pathogen, *Neozygites floridana*. The fungal pathogen is the more effective natural enemy, often killing infected mites within 1 to 3 days. Infected mites appear waxy or cloudy before they die, and the cadaver becomes a dark gray-black, shrunken "mummy." In a study conducted in Iowa (Klubertanz et al. 1991), the spread of a fungal disease caused by a *Neozygites* species occurred only during sustained cool and humid weather. The same research effort documented 95% mite population decline in 6 days.

***Twospotted spider mites and injury to soybean.*** Twospotted spider mites usually accumulate on the undersides of soybean leaves, often amidst webbing. They insert the stylets of their mouthparts into leaf cells and suck out the contents. Feeding by twospotted spider mites on soybean plants reduces photosynthetic capacity and chlorophyll content of the leaves. Water loss through the feeding wounds results in moderate to severe leaf water stress.

Symptoms of feeding by spider mites appear first as small, yellow spots; numerous spots create a stippling effect. Extensive stippling turns the leaves yellow, which eventually turn bronze in color, then turn brown, shrivel, and die, often dropping from the plants. Severely injured plants are stunted and may be completely defoliated. Yellow areas along field edges or within the field often identify the locations of initial infestations of spider mites, which will spread through the field if the mites are not controlled. In soybean fields infested with spider mites during late vegetative and early reproductive growth, yield reductions of 40 to 60% have been documented. However, the response of soybean yield to feeding by twospotted spider mites still is not well known and varies with the influence of other factors, e.g., direct effects of drought on soybean growth.

***Twospotted spider mites and weeds.*** Twospotted spider mites are generalist plant feeders with more than 900 recorded host plants (Agrawal 2000), including many weeds species. Consequently, the presence of weeds in crop ecosystems encourages the establishment of twospotted spider mite infestations (Brandenburg and Kennedy 1987, Kennedy and Storer 2000, Steinkraus et al. 2003). In the spring when environmental conditions favor an increase in densities of spider mites, the mites move from weeds on which females overwintered to adjacent plants, which include soybean and other crop species. As a result, spider mite infestations often begin along field margins bordered by weeds. This was the typical pattern of infestation that occurred during the drought in 1988. However, if weeds within the fields grow in the spring before they are killed with herbicides, spider mite infestations may be more widely distributed in crop fields (Steinkraus et al. 2003).

***Twospotted spider mites and drought.*** In 1983, applications of miticides to control twospotted spider mites occurred primarily in late July and August. In 1988, however, the onset of twospotted spider mite infestations occurred relatively early in the summer, beginning with reports of spider mites destroying clover in early June (Gray et al. 1989). Miticide applications continued throughout the summer as drought conditions persisted.

In an attempt to understand the relationship between twospotted spider mites and soybean physiology during drought conditions, Gray et al. (1989) conducted an experiment in a soybean field on the South Farm in Urbana-Champaign. The researchers learned that infestations of spider mites reduced the rate of photosynthesis, increased stomatal resistance, reduced the rate of transpiration, and decreased the amount of chlorophyll in injured leaves. More recently, the results from experiments conducted by Haile and Higley (2003) also revealed that spider mite injury caused a significant reduction in photosynthesis, stomatal conductance, transpiration, and chlorophyll content in soybean.

Gray et al. (1989) developed an injury scale that correlated better than densities of spider mites with soybean physiological parameters. They suggested that assessment of the average level of leaf injury in a field might be a better method for making a control decision than estimating the density of spider mites on soybean leaves. The current published economic threshold in Illinois was the product of this research effort: "Treat when 20 to 25% discoloration is noted before pod set, or 10 to 15% discoloration after pod set" (Cook et al. 2005).

The scientific literature published before and after the Gray et al. (1989) report was published contains conflicting information about the impact of moisture stress, temperature, and other factors on populations of twospotted spider mites. It is possible that the host plant on which spider mites occur may influence research results. Hollingsworth and Berry (1982) found that densities of twospotted spider mites increased more rapidly on peppermint plants that were under moisture stress than on nonstressed plants. However, Klubertanz et al. (1990) indicated that the results of their study of twospotted spider mites in soybean did not support the traditional belief that plant stress and the occurrence of heavy, driving rains are important factors in spider mite population dynamics. More recently, White and Liburd (2005) found that low soil moisture and temperatures >27°C (81.6°F) promoted development of twospotted spider mites on strawberries. From experiments conducted in soybean fields in Nebraska, Haile and Higley (2003) suggested that soil moisture improved soybean tolerance to spider mite injury.

Although the causes for outbreaks of twospotted spider mites in soybean when drought conditions prevail have been conflicting, most soybean producers understand that spider mites usually are problematic during hot, dry weather. So, concerns about twospotted spider mites were justified in Illinois as early as June 2005 when drought conditions persisted in some areas.

## Twospotted Spider Mites—Now (2005)

In an article in issue number 11 (June 3, 2005) of *the Bulletin*, Nafziger (2005) discussed the onset of a "mild drought" (a meteorological definition). In that same issue of *the Bulletin*, Steffey (2005a) reported his first observation of a small infestation of twospotted spider mites in a field of VC-stage soybean in Ford County. In some areas of the field, spider mites had moved from dying henbit (*Lamium amplexicaule*) plants after Roundup had been sprayed. Webbing, mite eggs, and a few mites were still visible on the dying henbit.

The association between a twospotted spider infestation and henbit was detected again in a no-tillage soybean field near Tolono in Champaign County (Steffey 2005b). Following are quotes from the article in issue number 14 (June 24, 2005) of *the Bulletin*. "It was apparent in the field I visited that the patches of spider mite infestations were associated with patches of henbit that had been killed with Roundup early this spring. In relatively 'healthy' areas of the field, we observed very few dead henbit plants. However, in heavily infested areas, dead henbit plants were common. No fall burndown herbicides were applied to the field in 2004, so some late-season weeds (e.g., henbit) were present. In the spring of 2005, Roundup was applied to the Roundup Ready soybeans just as the seedlings were emerging. Henbit was among the most common weeds in the field. As you may recall, I mentioned that I observed spider mites infesting henbit in a field in Ford County in May, the first spider mite-infested field I visited this year ('Twospotted Spider Mites in Soybeans Add Another Level of Concern,' issue no. 11, June 3, 2005). In both situations, and likely in others, the spider mites moved from the dying henbit onto healthy soybeans when the soybean plants were quite small.

"Some people have reported that twospotted spider mites are more common in no-till fields than in tilled fields. This may have a direct correlation with the presence or absence of henbit or other weeds on which female spider mites overwintered. Adjacent to the spider mite-infested field (separated only by turn rows) was a field of soybeans that had been tilled this spring. There were no obvious signs of spider mite infestation in the tilled field, although the spread of the mites in the no-till field will likely be a source of future infestation if a miticide is not applied soon."

At Western Illinois University (McDonough County), an experiment to examine the effects of fall-applied herbicides on weed infestations was conducted by one of the authors (Roskamp). In fall 2004, the study area was infested with common chickweed, *Stellaria media*, a winter annual weed. Canopy EX was applied to the appropriate plots on November 17, 2004. Chickweed was completely controlled with Canopy EX, so sprayed plots were chickweed-free in 2005. Plots that were not treated with herbicide during fall 2004 were infested with chickweed in 2005 and were treated with glyphosate on June 14.

Although populations of twospotted spider mites were not assessed in the experiment in 2005, spider mite infestations were largely absent in plots in which chickweed had been controlled with fall-applied herbicides. In chickweed-infested plots treated with glyphosate in June, spider mite infestations caused noticeable injury to soybean. These plots produced significantly lower yields than the plots to which herbicides had been applied the previous fall. Although weed competition may have contributed to the lower yields, the author of the study believed that yield reduction was due primarily to the spider mite infestation.

Henbit has been reported as a host of twospotted spider mites in cropping systems in the southeastern United States (Margolies and Kennedy 1985), so the occurrence of spider mites in Illinois soybean fields infested with henbit in 2005 was not novel. Chickweed also is a host for twospotted spider mites. The prevalence of no-till farming, as well as the widespread planting of herbicide-tolerant crops, enables growth of some weed species throughout the field until the weeds are killed with glyphosate. Consequently, spider mites may also be distributed throughout the fields, moving from the dying weeds to the crop plants (Steinkraus et al. 2003).

The soybean field infested with twospotted spider mites in Champaign County provided an opportunity to conduct an experiment to determine the effects of two miticides and the time of their application on spider mite densities and soybean yield. Following is a discussion of the experiment and its results.

***Materials and methods.*** The experiment was established on 24 June, 2005, in a field of soybean infested with twospotted spider mites. At the time of establishment, soybean plants in large patches in the field had symptoms of severe injury caused by spider mites (e.g., stunted plants and yellow or bronzed leaves). One of the authors (Schaeffer) discovered the spider mite infestation on June 20. Except for the plot area, the field was sprayed on June 22 with Dimethoate 400 (1 pt per acre) for control of spider mites.

Later in the summer, a spider mite infestation developed in an adjacent field of soybean that had been tilled the previous fall (2004). The infestation was discovered along the edges of the field by one of the authors (Schaeffer) on July 10. Although we did not conduct a fully developed experiment in that field, we established miticide-treated and nontreated strips within the field so that we could compare results from a "conventionally tilled" (south) field with results from our experiment in the "no-till" (north) field. Information about both plots is presented in Table 1.

***North field***—The plots in the north field were arranged in a randomized complete block with four replications. The following eight treatments were included in each replication:

- Dimethoate applied early (24 June)
- Dimethoate applied late (8 July)
- Dimethoate applied twice (24 June and 8 July)
- Lorsban applied early (24 June)
- Lorsban applied late (8 July)
- Lorsban applied twice (24 June and 8 July)
- Untreated check × 2

Each plot measured 20 ft × 30 ft. Plots treated early or late were treated only once with the specified miticides;

**Table 1. Field information, twospotted spider mite experiment, Champaign County, IL, 2005**

| Agronomic information | No-till experiment (north field) | Conventionally tilled field (south field) |
|---|---|---|
| Planting date | 8 May | 5 May |
| Variety | Kruger 379 | NK S-39K6 RR |
| Herbicides | 22 oz Roundup OMAX on 16 May<br>1½ qt Glyphosate 4 on 20 June | 22 oz Roundup OMAX on 12 June |
| Tillage | No tillage; soybean planted into corn stubble | Chiseled in fall 2004, cultivated in spring 2005 |
| Previous crop | Corn | Corn |
| Row spacing | 15 inches | 15 inches |

plots treated both early and late were sprayed on both dates with the specified miticide. Both Dimethoate 400 and Lorsban 4E were applied at a rate of 1 pt per acre (in 15 gal of water per acre) with a 10-ft spray boom at a pressure of 32 psi.

Densities of spider mites were estimated in each plot in each replication on six dates—30 June, 7 July, 14 July, 21 July, 28 July, and 4 August. Along a diagonal transect in each plot, five randomly selected leaflets were removed from the middle of the canopy. The five leaflets from each plot were placed in plastic bags and returned to the laboratory so that the numbers of mites could be counted. Each leaflet in each sample was lowered three times into a mite-brushing machine (Leecom Enterprises, MiWuk Village, CA). The mites were brushed from the leaflets onto a rotating, 5-inch diameter glass plate onto which a drop of dishwashing liquid had been spread. After the mites had been brushed from all five leaflets in a sample, the glass disks were placed under a microscope, and all living, legged mites (i.e., nymphs, adults) on one-quarter of the disk were counted. The number of mites counted was multiplied by 4 and recorded.

Plant heights were estimated on the same dates when spider mite densities were estimated. Along a diagonal transect in each plot, the heights of 10 randomly selected plants were measured with yardsticks from the ground to the topmost leaves, which were pulled upright for the measurement. All measurements of plant heights were recorded in the field.

Yields of all plots were estimated by harvesting a 15 ft × 30 ft strip on 10 October, 2005, with a model 1620 Case International combine. The weight per plot was adjusted to bushels per acre at 13% moisture, with 60 lb = 1 bushel of soybean.

An analysis of variance (SAS version 9.1) was conducted for numbers of mites, plant heights, and yields. Means were separated with Tukey's mean separation test.

***South field***—On 20 July, 2005, all but a 160 ft × 160 ft area of the south field was sprayed with Dimethoate 400 (1 pt per acre) to control an infestations of twospotted spider mites. Half of the untreated area was sprayed with Warrior 1EC (3.84 fl oz per acre) on 3 August. The other half of the area remained untreated.

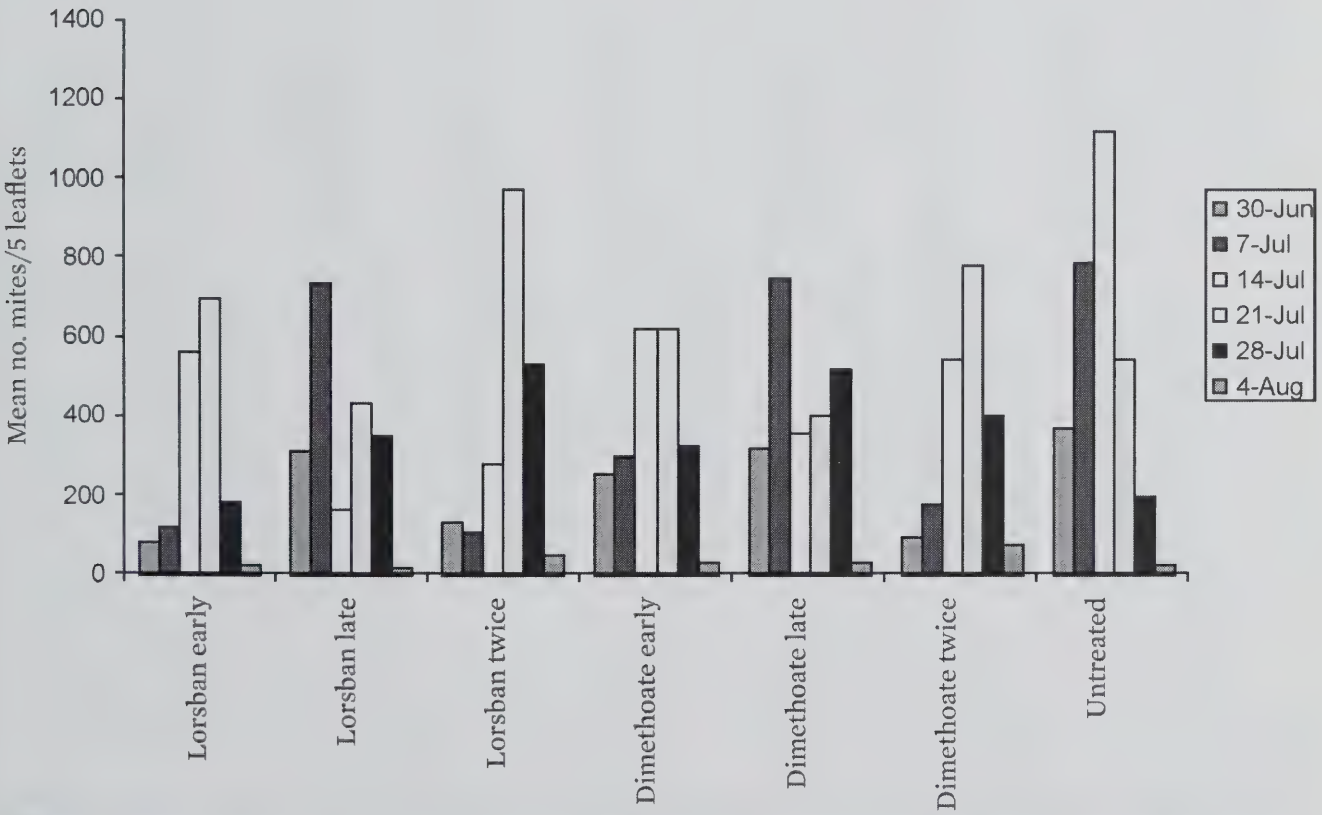



**Figure 1. Mean numbers of twospotted spider mites per 5 leaflets on six sampling dates, Champaign County, IL, 2005.**

Densities of spider mites were estimated in the Dimethoate-treated area, Warrior-treated area, and untreated area on three dates—21 July, 28 July, and 4 August. The procedure used to estimate mite densities was the same as described for the north field, except 10 leaflets were sampled. Yields of the Warrior-treated and untreated areas were estimated by harvesting a 15 ft × 150 ft strip on 10 October, 2005. The yield from the Dimethoate-treated area was estimated by the cooperating producer. Because the treatments in this field were neither replicated nor randomized, statistical analysis was not conducted.

***Results and discussion.*** The mean numbers of twospotted spider mites per five soybean leaflets in each treatment on each of six sampling dates in the north field are shown in Figure 1. The densities of spider mites in the two untreated check plots were averaged for display in Figure 1. The density of spider mites in the untreated check plots peaked on 14 July at 1,122 mites per five leaflets, after which the density of mites per five leaflets began to decline. Early applications (24 June) of both Lorsban and Dimethoate prevented rapid increase in densities of spider mites until 14 July. Mite densities in the plots not treated until 8 July increased at approximately the same rate as the increasing densities in the untreated check from 30 June to 7 July. The densities in the late-treated plots declined markedly from 7 July to 14 July after the miticides were applied on 8 July. However, the densities of mites in the late-treated plots resurged by 21 July

In the plots treated twice, the numbers of mites per five leaflets on 14 July were roughly equivalent to the numbers of mites in the plots treated early. However, the densities of mites in the plots treated twice with either Lorsban or Dimethoate increased after the second treatment and reached relatively large numbers by 21 July—971 mites per five leaflets in the Lorsban-treated plots, and 782 mites per five leaflets in the Dimethoate-treated plots.

Densities of spider mites began to decline in almost all plots by 28 July. The twospotted spider mite population in the entire plot area "crashed" by 4 August.

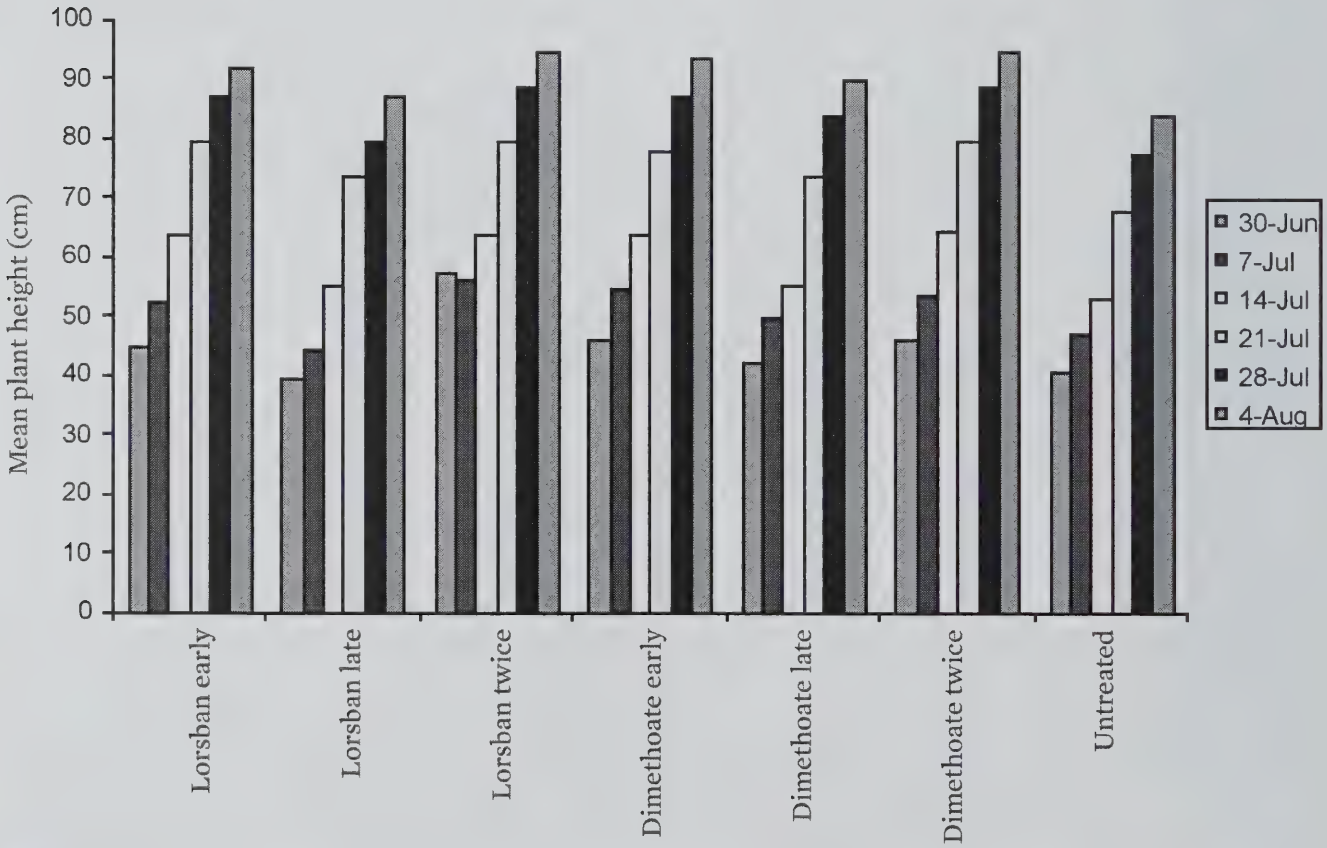



**Figure 2. Mean heights (cm) of soybean plants infested with twospotted spider mites on six sampling dates, Champaign County, IL, 2005.**

The mean heights of soybean plants in each treatment on each of six sampling dates in the north field are shown in Figure 2. The plant heights in the two untreated check plots were averaged for display in Figure 2. The mean heights on 30 June reveal the initial differences in heights resulting from the patchiness of the spider mite infestation in the field. However, plant heights in the miticide-treated plots began to equalize in plots treated early (24 June) and twice (24 June and 8 July). Plant heights remained somewhat shorter in the plots treated late (8 July) than in the plots treated early and twice throughout most of the sampling period. The mean plant height in the untreated check plots was shorter than the mean plant heights in the miticides-treated plots on 28 July and 4 August.

Analysis of variance revealed significant differences in mean numbers of spider mites among treatments on specific sampling dates in the north field, but no significant differences among treatments when numbers of spider mites were combined over sampling dates (Table 2). The LSD ($\alpha = 0.05$) of 1.38 cm for mean plant height indicates that there were significant differences in plant heights between treatments in the north field (Table 2). For most plots, the mean plant heights in the untreated check plots were significantly shorter than the mean plant heights in the treated plots. Also, the mean plant height in the plots treated late with Lorsban and Dimethoate were significantly shorter than the mean plant heights in the plots treated early and twice with the same miticide.

The LSD ($\alpha = 0.05$) of 7.72 bushels per acre for yield indicates that there were some significant differences between treatments in the north field (Table 2). The mean yields in the two untreated checks were significantly less than the mean yields in the plots treated both early and late with Dimethoate. The mean yields in the Lorsban-treated and Dimethoate-treated plots were not significantly different. The mean yields in the plots treated early, late, and twice with each miticide were not significantly different.

Table 3 shows the mean densities of spider mites in plots in the north field treated early, late, and twice, regardless of miticide applied, and in untreated plots on each sampling date. The data reveal that on 30 June and 7 July, the mean densities of mites in the untreated check plots were greater than the mean densities of mites in the plots treated early and twice, but not significantly greater than the mean densities of mites in the plots treated late. Mite population densities resurged by 14 July in the plots treated early and twice, so mean densities of mites in the untreated plots were not significantly different from the mean densities of mites in the plots treated early and twice. However, the mean density of mites in the late-treated plots on 14 July was significantly smaller than the mean density of mites in the untreated check. There were no significant differences in densities of mites in the untreated plots and plots treated early, late, and twice on 21 July. On 28 July, the mean density of mites in the untreated plots was significantly smaller than the mean densi-

**Table 2. Mean numbers of twospotted spider mites, mean plant heights, and mean yields per treatment, north field, Champaign County, IL, 2005**

| Treatment | Date of miticide application | | Mean no. spider mites per 5 leaflets | Mean plant height (cm) | Mean yield (bu/A) |
|---|---|---|---|---|---|
| Dimethoate applied early | June 24 | — | 358.33 | 70.39 | 61.20 |
| Dimethoate applied late | — | July 8 | 394.21 | 65.59 | 62.10 |
| Dimethoate applied twice | June 24 | July 8 | 347.21 | 70.92 | 59.70 |
| Untreated | — | — | 506.17 | 63.69 | 53.24 |
| Lorsban applied early | June 24 | — | 291.33 | 69.95 | 55.97 |
| Lorsban applied late | — | July 8 | 334.13 | 63.13 | 58.40 |
| Lorsban applied twice | June 24 | July 8 | 345.67 | 71.41 | 58.04 |
| Untreated | — | — | 505.83 | 59.53 | 52.75 |
| LSD, $\alpha = 0.05$ | | | ns | 1.38 | 7.72 |

**Table 3. Mean numbers of twospotted spider mites per treatment, north field, Champaign County, IL, 2005**

| | Mean no. spider mites per 5 leaflets[1] | | | |
|---|---|---|---|---|
| Sampling date | Miticide applied early[2] | Miticide applied late[3] | Miticide applied twice[1,2] | Untreated |
| June 30 | 207.49 bc | 307.39 ab | 114.00 c | 373.0 a |
| July 7 | 210.00 b | 743.50 a | 144.50 b | 784.0 a |
| July 14 | 590.00 a | 262.00 b | 412.00 ab | 1,121.5 a |
| July 21 | 660.50 a | 420.00 a | 876.50 a | 543.5 a |
| July 28 | 254.00 a | 434.00 a | 467.50 a | 193.5 b |
| August 4 | 27.00 a | 18.14 a | 64.00 a | 20.5 a |

[1] Means followed by different letters in the same row are significantly different at $\alpha = 0.05$. Data were transformed using Log10(mites + 10) for statistical analysis. The data presented in the table are not transformed.

[2] Miticide application on 24 June, 2005.

[3] Miticde application on 8 July 2005.

ties of mites in the plots treated early, late, and twice. On 4 August, there were no significant differences in densities of spider mites among the plots.

Data from the south field (nonreplicated treatment strips) are shown in Table 4. The infestation of twospotted spider mites developed much later in the season in the south field than in the north field, so the numbers of mites in the different strips were relatively small on all sampling dates. The maximum difference between yields was 2.2 bushels per acre between the yield of the untreated strip (46.8 bushels per acre) and the yield of the Dimethoate-treated strip (49 bushels per acre). Interestingly, the yields in the south field were smaller than the yields in the different plots in the north field, including the yields in the untreated plots.

Following are some conclusions that can be drawn from the experiment we conducted in Champaign County in 2005:

- Miticide application reduced densities of twospotted spider mites for at least 1 week after application.
- Densities of twospotted spider mites resurged in 1 to 2 weeks after a single application of a miticide, depending upon the timing of application.
- The timing of miticide application (early or late) influenced the population dynamics of twospotted spider mites, but ultimately had no effect on soybean yield.
- Densities of twospotted spider mites increased after a second application of the same miticide, although the increased densities ultimately had no effect on soybean yield.
- The twospotted spider mite population in the plot area in Champaign County "crashed" by late July. We did not determine the cause for the population "crash."
- Twospotted spider mites reduce soybean plant height when the mites are not controlled with miticides.
- Generally, application of a miticide to control twospotted spider mites provided a soybean yield benefit.
- Two applications of the same miticide did not provide a yield benefit different from one application of the miticide.

**Table 4. Numbers of twospotted spider mites and yields per treatment, south field, Champaign County, IL, 2005**

| | Mean no. spider mites per 10 leaflets | | | |
|---|---|---|---|---|
| Treatment | 22 July | 29 July | 5 August | Yield (bu/A) |
| Dimethoate 400 | 0.7 | 2.2 | 2.5 | 49.0 |
| Warrior 1EC | 8.7 | 3.0 | 0.4 | 47.6 |
| Untreated | 8.7 | 3.0 | 2.8 | 46.8 |

## Twospotted Spider Mites—Tomorrow

The drought conditions that prevailed in much of Illinois in 2005 were conducive for the development of significant infestations of twospotted spider mites in soybean fields. Infestations of spider mites also developed in other midwestern states in 2005, albeit later in the season than they developed in Illinois. We should expect that droughts in the future likewise will encourage development of spider mite infestations in soybean.

***Twospotted spider mites, weeds, and herbicides.*** Based upon many observations in 2005, spider mite infestations in Illinois developed relatively early in fields in which winter annual weeds (e.g., common chickweed, henbit) grew in the spring before they were killed with glyphosate. This situation has been noted by other entomologists in other areas of the county (Steinkraus et al. 2003). Preliminary evidence suggests that tillage in the fall or application of an herbicide in the fall will kill winter annual weeds, reducing the in-field habitat for overwintering female spider mites. The destruction of winter annual weeds before spider mites become active in the spring may delay the development of spider mite infestations throughout a field, and may ultimately reduce the impact of spider mites on soybean yield during drought years.

The use of glyphosate to control weeds in Roundup Ready soybean in Illinois is widespread. Evidence from our experiment suggests that delayed weed control in soybean fields could enable twospotted spider mites to establish early in the spring when soybean plants are small. Also, some laboratory research conducted in Iowa (Morjan et al. 2002) has shown that some formulations of glyphosate have fungicidal activity against fungal organisms that help suppress arthropod pests, including *Neozygites floridana*, the most important fungal organism infecting twospotted spider mites in the Midwest (Klubertanz et al. 1991). *Neozygites floridana* was susceptible to all of the glyphosate formulations tested—Roundup Ready-To-Use, Roundup Ultra, Roundup Ultra 2, Roundup Original, Roundup Pro, Roundup RT, and Roundup Ultra RT. Glyphosate alone did not have fungicidal activity against any of the fungi tested.

Based upon the results from Morjan et al. (2002), it is possible that the use of glyphosate formulations to control weeds in soybean could promote the early development of spider mite infestations during hot, dry weather. In addition, some producers have begun the practice of tank mixing Roundup herbicide with an insecticide to control soybean aphids in June, although this approach toward soybean aphid control is discouraged. A survey conducted by O'Neal and Johnson (2005) revealed that 43% of 596 commercial pesticide applicators in Iowa tank mixed an insecticide with Roundup in 2004. Pyrethroid insecticides often are used for control of soybean aphids, and these insecticides are known to "flare" spider mite populations in the drier western states. Consequently, the practice of tank mixing a pyrethroid insecticide with Roundup could accelerate development of twospotted spider mite infestations by killing natural enemies of the spider mites.

***Twospotted spider mites and miticides.*** The data from our experiment indicated that there was no soybean yield benefit gained by applying the same miticide twice (24 June and 8 July) to control twospotted spider mites. The cost of the second application was not offset by additional yield in the plots treated twice with either Lorsban or Dimethoate. From an ecological perspective, a second application of the same miticide, or possibly different miticides, increases the potential for development of miticide resistance in twospotted spider mite populations. In a laboratory experiment, Yang et al. (2002) tested the effects of repeated applications of two pyrethroids—bifenthrin (active ingredient of Capture 2EC) and lamda-cyhalothrin (active ingredient of Warrior 1EC)—and one organophosphate—dimethoate. After 10 cycles of exposure, susceptibility of twospotted spider mites to bifenthrin, lamda-cyhalothrin, and dimethoate decreased 14.8-, 5.7-, and 104.7-fold, respectively, relative to the nontreated strain of twospotted spider mites. The reduced susceptibility to dimethoate remained stable for 3 months in the absence of selection pressure. The results also suggested that there may be cross-resistance between bifenthrin (not labeled for use on soybean) and dimethoate. The results from Yang et al. (2002) and the lack of yield benefit from two applications of a miticide in our experiment suggest that multiple applications of miticides to control twospotted spider mites are economically and ecologically unwise. Also, widespread application of insecticides to control soybean aphids could have an effect of populations of twospotted spider mites.

Twospotted spider mites are polyphagous, enhancing their ability to change host plants, which, in turn, enhances their successful colonization on multiple hosts (Navajas 1998). Also, the susceptibility of twospotted spider mites to miticides differs depending upon the host plants on which the mites are feeding (Yang et

al. 2001). Consequently, the interaction of twospotted spider mites, hosts (crops and weeds), and miticides could dramatically influence future management strategies.

***Twospotted spider mites and neonicotinoid insecticides.*** The registration of imidacloprid (active ingredient of Gaucho) and thiamethoxam (active ingredient of Cruiser) for use in soybean seed treatments has established an interest in the use of these neonicotinoid insecticides for control of bean leaf beetles and soybean aphids. It is likely that the acres of soybean treated with neonicotinoids will increase over time. However, the widespread use of these products could have unforeseen consequences. In a laboratory experiment in Washington, James and Price (2002) determined that fecundity of twospotted spider mite females fed on bean discs cut from a systemically treated (with imidacloprid) bean plant increased. Egg production increased 6 days after the mites fed on the leaf discs and lasted until about 18 days after exposure. Longevity of the mites was significantly greater in mites that ingested imidacloprid than in mites not exposed to imidacloprid. In contrast, a greenhouse study in Germany (Ako et al. 2004) revealed that field-relevant dose rates of four neonicotinoid insecticides (including imidacloprid and thiamethoxam) most often caused a significant decrease in oviposition of twospotted spider mites between day 4 and 14 after adult emergence. This resulted in an overall significantly reduced number of eggs laid by treated females during the 16 days of the oviposition period. The reasons for these contrasting results were not revealed in either paper, although differences in testing methods and potential indirect effects of neonicotinoid insecticides were discussed.

***Management of twospotted spider mites.*** All of the research cited in this report and the results from our experiment in 2005 suggest that effective management of twospotted spider mites in soybean requires understanding of many factors and use of several management tactics. Environmental conditions, the presence or absence of weeds, weed control practices, the number of miticide applications, and the use of neonicotinoid insecticides all may influence the development of twospotted spider mite infestations and their impact on soybean yield. All of these factors emphasize the importance of using integrated pest management (IPM) strategies to ensure effective management of twospotted spider mites in soybean when drought conditions prevail.

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## References

Agrawal, A. A. 2000. Host-range evolution: Adaptations and trade-offs in fitness of mites on alternative hosts. Ecology 81: 500–508.

Ako, M., C. Borgemeister, H.-M. Poehling, A. Elbert, and R. Nauen. 2004. Effects of neonicotinoid insecticides on the bionomics of twospotted spider mite (Acari: Tetranychidae). Journal of Economic Entomology 97: 1587–1594.

Brandenburg, R. L., and G. G. Kennedy. 1987. Ecological and agricultural considerations in the management of twospotted spider mite (*Tetranychus urticae* Koch). Agricultural Zoology Reviews 2: 185–236.

Colwell, C. E. 1984. Insect situation and use of insecticides in 1983, pp. 110–125. *In* Thirty-Sixth Illinois Custom Spray Operators Training School Manual. Cooperative Extension Service, University of Illinois, Urbana-Champaign.

Cook, K. A., K. L. Steffey, and M. E. Gray. 2005. Insect pest management for field and forage crops, pp. 1–28. *In* 2005 Illinois Agricultural Pest Management Handbook, University of Illinois Extension, Urbana-Champaign

Gray, M., G. Pepper, and J. Fredericks. 1989. The spider mite outbreak of 1988: Did we learn enough to improve our decision-making capabilities? pp. 31–40. *In* Proceedings of the Illinois Agricultural Pesticides Conference '89. Cooperative Extension Service, University of Illinois, Urbana-Champaign.

Haile, F. J. and L. G. Higley. 2003. Changes in soybean gas-exchange after moisture stress and spider mite injury. Environmental Entomology 32: 433–440.

Hollingsworth, C. S., and R. E. Berry. 1982. Twospotted spider mite (Acari: Tetranychidae) in peppermint: Population dynamics and influence of cultural practices. Environmental Entomology 11: 1280–1284.

James, D. G., and T. S. Price. 2002. Fecundity in twospotted spider mite (Acari: Tetranychidae) is increased by direct and systemic exposure to imidacloprid. Journal of Economic Entomology 95: 729–732.

Kennedy, G. G., and N. P. Storer. 2000. Life systems of polyphagous arthropods in temporarily unstable cropping systems. Annual Review of Entomology 45: 467–493.

Klubertanz, T. H. 1994. Twospotted spider mite, pp. 92–95. *In* Higley, L. G., and D. J. Boethel (eds.), Handbook of Soybean Insect Pests. Entomological Society of America, Lanham, MD.

Klubertanz, T. H., L. P. Pedigo, and R. E. Carlson. 1990. Effects of plant moisture stress and rainfall on population dynamics of the twospotted spider mite (Acari: Tetranychidae). Environmental Entomology 19: 1773–1779.

Klubertanz, T. H., L. P. Pedigo, and R. E. Carlson. 1991. Impact of fungal epizootics on the biology and management of the twospotted spider mite (Acari: Tetranychidae) in soybean. Environmental Entomology 20: 731–735.

Margolies, D. C., and G. G. Kennedy. 1985, Movement of the twospotted spider mite, *Tetranychus urticae*, among hosts in a corn–peanut agroecosystem: Entomologia Experimentalis et Applicata 37: 55–61.

Morjan, W. E., L. P. Pedigo, and L. C. Lewis. 2002. Fungicidal effects of glyphosate and glyphosate formulations on four species of entomopathogenic fungi. Environmental Entomology 31: 1206–1212.

Nafziger, E. 2005. Is it drought yet? *In* the on-line version of the Bulletin, http://www.ipm.uiuc.edu/bulletin/article.php?id=314. University of Illinois Extension, Urbana-Champaign.

Navajas, M. 1998. Host plant associations in the spider mite *Tetranychus urticae* (Acari: Tetranychidae): Insights from molecular phylogeography. Experimental & Applied Acarology 22: 201–214.

O'Neal, M., and K. Johnson. 2005. Survey: Are insecticide/herbicide tank mixes commonly used? Pp. 132–133. *In* Integrated Crop Management, IC-494 (16), June 27. Iowa State University Extension, Ames.

Pike, D. R., E. L. Knake, D. E. Kuhlman, M. D. McGlamery, and N. R. Pataky. 1990. Pesticide use in Illinois: Results of a 1988 survey of major crops. Circular 1301, Cooperative Extension Service, University of Illinois, Urbana-Champaign.

Steffey, K. 2005a. Twospotted spider mites in soybeans add another level of concern. *In* the on-line version of the Bulletin, http://www.ipm.uiuc.edu/bulletin/article.php?id=307. University of Illinois Extension, Urbana-Champaign.

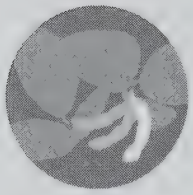
Steffey, K. 2005b. Don't wait to begin examining soybean fields for spider mites. *In* the on-line version of the Bulletin, http://www.ipm.uiuc.edu/bulletin/article.php?id=340. University of Illinois Extension, Urbana-Champaign.

Steinkraus, D., J. Zawislak, G. Lorenz, B. Layton, and R. Leonard. 2003. Spider mites on cotton in the Midsouth. University of Arkansas, Division of Agriculture, Fayetteville.

White, J. E., and O. E. Liburd. 2005. Effects of soil moisture and temperature on reproduction and development of twospotted spider mite (Acari: Tetranychidae) in strawberries. Journal of Economic Entomology 98: 154–158.

Yang, X., D. C. Margolies, K. Y. Zhu, and L. L. Buschman. 2001. Host plant-induced changes in detoxification enzymes and susceptibility to pesticides in the twospotted spider mite (Acari: Tetranychidae). 94: 381–387.

Yang, X., L. L. Buschman, K. Y. Zhu, and D. C. Margolies. 2002. Susceptibility and detoxifying enzyme activity in two spider mite species (Acari: Tetranychidae) after selection with three insecticides. Journal of Economic Entomology 95: 399–406.



# Prevalent Soybean Diseases: Current Management and Future Strategies

Jason P. Bond and Michael E. Schmidt

In the ever-changing landscape of crop production, one factor that remains consistent is the threat of yield-limiting pathogens. Today, soybean producers face a spectrum of pathogens that would have been inconceivable to previous generations. There are more than 25 pathogens capable of causing soybean yield loss in Illinois. It is estimated that the top 10 pathogens are responsible for annual yield losses averaging 1.8 million metric tons (Table 1).

Management practices are effective for many of the diseases listed in Table 1, and host resistance is preferred in most cases. Other management strategies include chemical control and cultural practices such as tillage, altering planting dates, and crop rotation. Current management strategies are limited, as highlighted in 2005 with the threat of Asian soybean rust influencing production decisions. Soybean rust may have disproportionately outweighed the concern for other diseases that cause annual yield losses in Illinois. Altering production decisions based solely on one disease can have dire consequences in on managing other pests. However, preventative methods for soybean rust also may provide benefits for management of other diseases. This report focuses on the current and future management of two soybean diseases and how their management may be influenced by soybean rust.

Sudden death syndrome (SDS) of soybean is caused by *Fusarium solani* f. sp. *glycines*. This disease has become a major problem in many soybean production areas in the United States. SDS was first identified in Illinois in 1979; however, the incidence and severity of SDS did not reach levels that caused concern among farmers until 1984. The pathogen infects soybean roots as early as 15 to 30 days after planting and continues throughout the season. The pathogen causes injury to the root system; however, the foliar phase of the disease results in severe yield loss. Symptoms of the foliar phase of the disease are the result of a toxin produced by the pathogen. The initial foliar symptoms are intermittent chlorotic spots that begin at or near the time of flowering. As the severity increases, the spots coalesce to form elongated, interveinal areas that become necrotic. In severe cases, defoliation and pod loss result in a bare stem with only upright petioles remaining. Epidemics of SDS are greatest when soil moisture is high and soil temperatures are low during the early reproductive stages of the soybean plant. Another factor that affects SDS severity in many areas is soil compaction. Soil compaction inhibits soil profile

**Table 1. Average reductions of soybean yields in metric tons due to diseases during 1999–2002 in Illinois**

| Disease | Annual yield loss (metric tons) |
|---|---|
| Soybean cyst nematode | 729,149 |
| Sudden death syndrome | 544,392 |
| Phytophthora rot | 148,283 |
| Charcoal rot | 146,202 |
| Seedling diseases | 56,157 |
| Brown spot | 43,420 |
| Virus | 37,767 |
| Brown stem rot | 34,378 |
| Pod and stem blight | 28,212 |

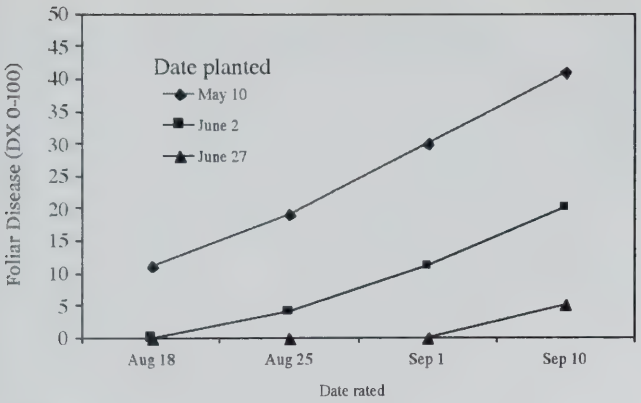



**Figure 1. Influence of planting date on sudden death syndrome.**

drainage and increases duration of soil saturation, both of which are favorable for SDS.

Before the availability of SDS-resistant varieties, management recommendations were limited to adjusting planting dates for fields with a history of SDS. By delaying the planting date, the disease severity can be decreased (Figure 1). Although this strategy still works, there are obvious liabilities in recommending that producers wait to plant fields because for concern over a disease that may or may not be severe a couple of months later. However, it is feasible to delay planting fields with a history of SDS until other fields on the farm are planted. Other cultural practices have been helpful in reducing the impact of SDS. Soil compaction can increase the incidence and severity of SDS because of its direct relationship with soil moisture. When compacted soils are disturbed by either subsoiling or by chisel plowing, SDS severity can be reduced by as much as 50%.

Genetic control is the single best management tool for SDS. The first cultivar with SDS resistance was 'Pharaoh', which was released in 1989. Since then, eight SDS-resistant varieties have been released by the Southern Illinois University at Carbondale (SIUC) breeding program. Most varieties available to producers in 2000 were susceptible to the disease (Table 2.) As a measure of progress in the breeding community, in just 4 years, the number of resistant varieties has increased greatly, and the number of highly susceptible varieties has decreased. Because of progress made over the past 10 years, a greater number of resistant varieties will be available in the future.

A recent trend has been earlier soybean planting dates (April 6 to April 30). In 2005, this trend was exacerbated and was partially because of producers hoping to avoid or reduce the impact of a late-season epidemic of soybean rust. Early planting has been shown to predispose plants to various seedling diseases and to SDS. If soybean rust becomes a recurring threat to producers, altering planting dates because of soybean rust may have dire consequences regarding management of other soybean diseases.

Frogeye leaf spot (FLS), caused by *Cercospora sojina*, has a worldwide distribution and was first reported in the United States in 1924. A recent survey of 30 counties in southern Illinois indicated that 75% of fields were affected by FLS. Yield loss caused by the disease can be disastrous. Studies in Alabama and in Indiana revealed that yield losses can exceed 20%. Although pods and stems may be infected, yield loss is primarily caused by reduction in leaf photosynthetic area, which leads to premature defoliation. The result is a reduction in seed size, quality, and germination rate.

The pathogen is genetically very variable, with at least 22 reported races of *C. sojina*. However, there is no published or accepted race scheme that adequately characterizes the populations of FLS that occur in the United States. The absence of pathogen race profiles has been a stumbling block in the development of resistant soybean varieties, and the years of idleness in this endeavor has resulted in the loss of *C. sojina* cultures and has retarded the establishment of a set of soybean differentials. Efforts to compare resistance genes in soybean have been thwarted by the unavailability of these cultures and differentials.

The Soybean Genetics Committee currently recognizes three genes that confer resistance to FLS. The $Rcs_3$ gene has been shown to confer resistance to all known

**Table 2. Performance of commercial varieties (maturity groups 3L, 4E, and 4L) regarding resistance or susceptibility to sudden death syndrome**

| | No. of varieties | |
|---|---|---|
| % of susceptible check | 2000 | 2004 |
| 0–20 | 41 | 86 |
| 21–40 | 60 | 137 |
| 41–60 | 64 | 71 |
| 61–80 | 60 | 37 |
| 81–100 | 53 | 9 |
| >100 | 24 | 1 |

isolates of the pathogen. This gene has provided stable control of FLS for southern soybean producers since its discovery in 1980s. However, conscious efforts to introgress this gene into northern varieties have not been made. Other soybean varieties are known to possess genes for resistance to FLS that are different from $Rcs_{1\text{-}3}$. Variety evaluations conducted by SIUC researchers and others have revealed that, in general, the northern varieties are more susceptible to FLS than the southern varieties. In 2004–2005, less than 15% of the varieties tested in Illinois and Missouri were resistant to FLS. However, these varieties were tested against a single isolate of the pathogen. Additional testing is needed to determine whether these varieties may be susceptible to other isolates.

Other than genetic control, the only recommendation for managing FLS is to apply foliar fungicides, which have always provided excellent management of FLS. The general recommendation is to apply fungicides at the R3–R4 plant growth stages. In Illinois, fungicide studies in 2005 revealed that chlorothalonil and strobilurin fungicides provided excellent control of FL. However, the two products differ in how they influence soybean yield.

The application of these fungicides at the appropriate growth stage may provide protection for not only FLS but also for soybean rust. In areas with a history of FLS, it will be easier to justify the costs of applying a preventative fungicide. In these situations, management of FLS in the early to mid-soybean reproductive stages may provide peace of mind regarding the threat of soybean rust at least for a brief time during the growing season.

## References


Athow, K. L., and A. H. Probst. 1952. The inheritance of resistance to frogeye leaf spot of soybeans. Phytopathology 42: 662–662.

Dashiel, K. E., and C. N. Akem. 1991. Yield losses in soybeans from frogeye leaf spot caused by *Cercospora sojina*. Crop Protection 10: 465–468.

Hilderbrand, K. K., S. K. Chong, O. Myers, Jr., Y. Lou, E. Varsa, E., and S. J. Indorante. 1998. Mapping soybean sudden death syndrome (SDS) as related to soil properties using global positioning system. Agronomy Abstracts, p.119. American Society of Agronomy, Madison, WI.

Luo, Y., O. Myers, D. A. Lightfoot, and M. E. Schmidt. 1999. Root colonization of soybean cultivars in the field by *Fusarium solani* f. sp. *glycines*. Plant Disease 83: 1155–1159.

Mian, M. A. R., H. R. Boerma, D. V. Philips, M. M. Kenty, G. Shannon, E. R. Shipe, A. R. Soffes Blount, and D. B. Weaver. 1998. Performance of frogeye leaf spot-resistant and susceptible near-isolines of soybean. Plant Disease 82: 1017–1021.

Roy, K. W. 1997. *Fusarium solani* on soybean roots: Nomenclature of the causal agent of sudden death syndrome and identity and relevance of *F. solani* form B. Plant Disease 81: 259–266.

Roy, K. W., J. C. Rupe, D. E. Hershman, and T. S. Abney. 1997. Sudden death syndrome of soybean. Plant Disease 81: 1100–1111.

Scherm, H., and X. B. Yang. 1996. Development of sudden death syndrome of soybean in relation to soil temperature and soil water potential. Phytopathology 86: 642–649.

Vick, C. M., S. K. Chong, J. P. Bond, and J. S. Russin. 2003. Response of soybean sudden death syndrome to subsoil tillage. Plant Disease 87: 629–632.

Wrather, J. A., and S. Koenning. 2002. Soybean disease loss estimates for the United States, 1996–2000. Delta Research Center, Missouri Agricultural Research Station. http://aes.missouri.edu/delta/research/soyloss.stm (August 4, 2002).

# Racism (Among Nematodes) in Soybean Pest Management

TERRY NIBLACK

The theme of this symposium is the perfect setting for reconsideration of the management of the soybean cyst nematode (SCN), *Heterodera glycines*. SCN management has been the subject of or impetus for research and development since its discovery in this country 50 years ago. Nearly everything we thought we knew about the nematode and its management has undergone change as it moved from the South to the Midwest and points north, particularly within the past 15 years. A review of the past, current, and projected thinking about all areas of SCN biology and management is available in a recently published book (Schmitt et al. 2004). The focus of this report is on one particular part of the SCN story, the "race" controversy, and its impact on soybean cropping systems. This subject is very timely and has major implications for SCN management in Illinois.

## Then

Almost immediately after the initial discovery of SCN, nematologists and soybean breeders noticed that field populations of the nematode showed differences in their abilities to attack resistant soybean genotypes (Ross 1962), but it was not until after release of the first SCN-resistant varieties that a way was developed to classify and study these differences (Golden et al. 1970). This was the birth of "races" as a framework to describe how different SCN populations behave.

A race of SCN was defined by its ability to attack a panel of four resistant soybean lines (Table 1). Having this framework facilitated the development of widely useful SCN-resistant varieties, which have prevented billions of dollars' worth of losses in soybean yields over the years. But although the race scheme was very useful for development of soybean varieties resistant to race 3, which cannot attack any resistant soybean (Table 1), it was a problem for many other research areas. For example, it did not account for all the variability in SCN populations that was observed in the field. To address this problem, the race scheme was expanded to 16 races—all the variability it could possibly account for (Table 2) (Riggs and Schmitt 1988). Yet the big problems, and many minor problems, remained. Four examples top the list: 1) 'Pickett' could not differentiate from 'Peking' any better than any other variety developed from Peking; 2) adding a differential to the scheme would double the number of races possible; 3) several more sources of SCN resistance had been discovered and used; and 4) "races" describe average *population* behavior, not *individual* genotypes.

This last problem is perhaps the biggest. It is a problem because the term "race" unintentionally implied something definable and stable. Most people have a very definite mental construct of "race." To most people, the term "race" suggests that there are differences between organisms that will allow us to distinguish individuals as members of one race or another. Human races are a good example and that idea is probably the model for this mental construct.

No model could be less applicable to SCN populations. There is absolutely no way to distinguish individual SCN as members of one race or another. The various scientific reasons for rejection of "race"-ism for SCN are numerous and complex (Niblack et al. 2002), but the main reason why soybean producers should reject it is that it is not useful for making management recommendations or decisions (Colgrove et al. 2002).

**Table 1. Races of SCN according to Golden et al. (1970)**

| Race | Pickett | Peking | PI 88788 | PI 90763 |
|---|---|---|---|---|
| 1 | No | No | + | No |
| 2 | + | + | + | No |
| 3 | No | No | No | No |
| 4 | + | + | + | + |

The soybean lines listed across the top row are referred to as "differentials."

Race determination is made on the basis of the *pattern* of "yes" and "no" ratings for each race. A "yes" rating is given if the number of females produced by an SCN population on a soybean differential is equal to or greater than 10% of the number produced on the standard susceptible cultivar Lee. If the number of females is less than 10%, a "no" rating is given.

**Table 2. Races of SCN according to the race determination schemes of Golden et al. (1970) and Riggs and Schmitt (1988)**

| Race | Pickett | Peking | PI 88788 | PI 90763 |
|---|---|---|---|---|
| 1 | – | – | + | – |
| 2 | + | + | + | – |
| 3 | – | – | – | – |
| 4 | + | + | + | + |
| 5 | + | – | + | – |
| 6 | + | – | – | – |
| 7 | – | – | + | + |
| 8 | – | – | – | + |
| 9 | + | + | – | – |
| 10 | + | – | – | + |
| 11 | – | + | + | – |
| 12 | – | + | – | + |
| 13 | – | + | – | – |
| 14 | + | + | – | + |
| 15 | + | – | + | + |
| 16 | – | + | + | + |

There are no differences between this table and Table 1, other than the substitution of terms ("+" for "yes" and "–" for "no") and the increase in the number of possible races. Races are determined in exactly the same way as described in Table 1.

## Now

Even though "race"-ism is not the best approach, we continue to need a good system of classification for SCN. The best of all possible options would be a molecular test, but we do not know enough about the genetic basis of the SCN–soybean interaction to develop such a test. Classification of SCN populations has at least three uses important to soybean producers: 1) as a framework for assessing and documenting differences among field populations or population change over time; 2) as a basis for development and evaluation of SCN-resistant varieties; and 3) as an aid to making management recommendations. A new classification system was proposed to bridge the gap between the end of "race"-ism and the future development of a reliable molecular test (Niblack et al. 2002).

The new system, called the HG Type test ("HG" stands for *Heterodera glycines*), is very simple (Table 3). The test involves extracting SCN from a given field and testing the nematodes' ability to attack each of the seven soybean lines listed in the Table. These lines are referred to as "indicator lines." The utility of the test is based on two facts: 1) all resistant varieties currently available to soybean growers in the United States can trace their resistance back to one of the seven indicator lines; and 2) if an SCN population can attack one or more of these lines, then it can attack any soybean variety developed from that line. These two facts make it possible to develop management recommendations based on the results of such a test.

*It is essential to remember that HG-typing is a way to classify the nematodes, not the soybean.* Many people in the seed industry have a good understanding of the problem of "race"-ism and willingly provide the identity of the source of resistance in their soybean varieties. Most of them also still put "race resistance" on their labels, however, to make sure that consumers (soybean producers) understand the correlation between the old and new systems. The transition will take time, and in the meantime, the search for a brighter tomorrow continues.

## Tomorrow

Conventional genetic wisdom in plant pathology states that if one matches a gene (or allele) for resistance in a host with a gene (or allele) for avirulence in the pathogen (i.e., a pathogen that cannot overcome the resistance), no disease will develop. The holy grail of many research programs on plant–pathogen systems is to be able to make such matches on demand. The SCN–soybean system is no exception.

On the soybean side: in the near future, perhaps companies will be able to publish not only sources of resistance as some of them do now but also specific alleles of genes for resistance that will tell farmers exactly what resistance is in the varieties they are buying. This seems perfectly feasible, because most companies now use marker-assisted selection in developing SCN-resistant varieties that may include allele discrimination. Less certain is the likelihood of genetically engineered SCN resistance. Although there are many points in the nematode life cycle and pathways in the plant that are candidate targets for genetic engineering, none have risen to the surface as near-term possibilities (at least, not in the public sector). Genetically engineered resistance would probably not be specific to any HG Type.

On the nematode side: although most people would say that the most desirable objective is to get rid of SCN entirely, it is also the least likely as long as soybeans are produced. In the foreseeable future, we will have a molecular test for virulence genes or alleles that allows us to predict the behavior of field populations and make reliable variety recommendations. Studies that will lead to something of this sort are well underway (Bekal et al. 2003, Lambert et al. 2005).

## Then, Now, and Tomorrow in Illinois

Fifteen years ago, only 88 of 102 counties in Illinois contained one or more fields known to be infested with SCN. A survey was conducted to describe the variability of SCN populations (Sikora and Noel 1991). The results showed that 64% of the SCN populations in Illinois were classified as "race 3," meaning that nearly two-thirds of the SCN in Illinois could not attack any known resistant varieties. Of the one-third that could attack resistant varieties, they were classified as races 1, 2, 4, and 5. Today, we would call most of them as "weak." In fact, only one SCN population (from Grundy County) was a "strong" race 1 that could be expected to damage race 3-resistant soybean.

The situation has changed considerably in the past 15 years. SCN has spread to every county in Illinois, including more than 80% of the soybean fields. A preliminary survey we conducted in 2004 showed that 74% of the SCN populations can attack most resistant varieties. We currently are conducting a more thorough survey in order to improve our understanding of the situation and chart our research for the future.

**Table 3. Indicator lines for HG Type classification of SCN field populations**

| No. | Indicator line |
|---|---|
| 1 | PI 548402 (Peking) |
| 2 | PI 88788 |
| 3 | PI 90763 |
| 4 | PI 437654 |
| 5 | PI 209332 |
| 6 | PI 89772 |
| 7 | PI 548316 (Cloud) |

Each line is a soybean plant introduction (PI) from the USDA Soybean Germplasm Collection. The HG Type of a field population of *H. glycines* is determined by the female index (FI) on each indicator line. As for race determination, FI = [(mean number of females on indicator line)/(mean number of females on the standard susceptible Lee 74)] × 100. If the FI is 10% or higher, the number of the indicator is used in the HG Type classification of the population. For example, a *H. glycines* population that produces FI > 10 on indicator lines 2, 5, and 7 is classified as an HG Type 2.5.7. Those populations that produce no FI > 10 are classified as HG Type 0. Actual FI values must also be reported, to distinguish among HG Types with the same numerical designations.

Today, Illinois growers have access to more information on soybean varieties than do most soybean growers in the United States. This is due to the availability of data from the Soybean Variety Trials and the SCN Screening Program, which are combined and brought to growers through the Varietal Information Program for Soybeans (VIPS). The database, available on the Web at http://web.aces.uiuc.edu/VIPS/, permits a level of matching soybean resistance and SCN virulence that can significantly improve variety choices for individual fields. The improvement can be enhanced by results from an Illinois SCN Type test, which is a subset of the HG Type test that includes only indicator lines 1, 2, and 4 (because these are the only three available in Illinois). We can, therefore, test an SCN population for its SCN Type, and recommend varieties based on the results.

## Conclusions

SCN is still spreading in the state and in the region, and it will continue to be one of the most economically important pests of soybean in the United States. As it spreads, SCN is also adapting to our best weapons against it—resistant varieties. As our understanding of this adaptation improves, our ability to limit losses

will increase. To aid achievement of these two goals—improved understanding and limited losses—it is time for us to banish "race"-ism from our thinking about SCN adaptation to resistant varieties. Continued use of the race concept for SCN will only impede progress.

## References


Bekal, S., T. Niblack, and K.N. Lambert. 2003. A chorismate mutase from the soybean cyst nematode *Heterodera glycines* shows polymorphisms that correlate with virulence. Molecular Plant-Microbe Interactions 16: 439–446.

Colgrove, A.L., G.S. Smith, R.D. Heinz, and T.L. Niblack. 2002. Lack of predictive value in *Heterodera glycines* race testing. Plant Disease 86: 1101–1108.

Golden, A.M., J. M. Epps, R.D. Riggs, L.A. Duclos, J.A. Fox, and R.L. Bernard. 1970. Terminology and identity of infraspecific forms of the soybean cyst nematode (*Heterodera glycines*). Plant Disease Reporter 54: 544–546.

Lambert, K.N., S. Bekal, L.L. Domier, T.L. Niblack, G.R. Noel, and C. A. Smyth. 2005. Selection of *Heterodera glycines* *chorismate mutase-1* alleles on nematode-resistant soybean. Molecular Plant-Microbe Interactions 18: 593–601.

Niblack, T.L., P.R. Arelli, G.R. Noel, C.H. Opperman, J. Orf, D.P. Schmitt, J.G. Shannon, G.L. Tylka, and T.L. Niblack. 2002. A new classification scheme for genetically diverse populations of *Heterodera glycines*. Journal of Nematology 34: 279–288.

Riggs, R.D., and D.P. Schmitt. 1988. Complete characterization of the race scheme for *Heterodera glycines*. Journal of Nematology 20: 392–395.

Ross, J.P. 1962. Physiological strains of *Heterodera glycines*. Plant Disease Reporter 46: 766–769.

Schmitt, D.P., R.D. Riggs, and J. A. Wrather (eds.) 2004. Biology and Management of the Soybean Cyst Nematode, 2nd Edition. Marceline, Missouri: Schmitt and Associates.

Sikora, E., and G.R. Noel. 1991. Distribution of *Heterodera glycines* races in Illinois. Supplement to Journal of Nematology 23: 624–628.

# Soybean Aphid and the Challenge of *Integrating* Recommendations within an IPM System

David W. Ragsdale, Erin W. Hodgson, Brian P. McCornack, Karrie A. Koch, Robert C. Venette, and Bruce D. potter

Aphids probably are of greater economic importance as crop pests worldwide than are defoliating insects (Blackman and Eastop 2000). This statement is based primarily on their cryptic nature of feeding, their small size, their high reproductive potential, and their ability to vector plant viruses (Clark and Perry 2002, Davis et al. 2005). Until aphids are extremely abundant, direct feeding injury often goes unrecognized, and indirect injury caused by infection by aphid-transmitted plant viruses occurs days or weeks after inoculation. Direct feeding injury by colonizing aphids is caused by the insertion of their needle-like mouthparts (stylets) directly into the vascular tissue (phloem) to remove plant sap. Photosynthate destined for seed production and plant growth is diverted into energy for insect growth. Aphids reproduce using a form of asexual reproduction called parthenogenesis, i.e., only females are present in the population, giving birth to live young (as many as 12 per day). Under optimal conditions, newly born nymphs mature into reproducing adults within as few as 5 days. This report focuses on the direct damage caused by soybean aphids, *Aphis glycines* Matsumura, in the North Central region.

## Soybean Aphid in the North Central Region

The soybean aphid, native to Asia, was first detected in North America in 2000 nearly simultaneously in 10 midwestern states. Before this discovery, insect or mite outbreaks in soybean were relatively uncommon in the Midwest, and integrated pest management (IPM) programs were restricted almost exclusively to defoliating and seed-feeding insects. Just 5 years after the initial discovery of soybean aphid, this insect now represents the most significant insect threat to soybean production in the north central states, far outpacing the importance of defoliators.

During fall 2005, an informal telephone and e-mail survey of extension entomologists in several states estimated that 15 million acres of soybean was treated for soybean aphid in 2005. Approximately 10% of the treated acres received a second application when aphid populations rebounded after the first application. The 2005 growing season is the third year of the past 5 years during which damaging aphid populations occurred over a large part of the north central states. Insecticide use added an estimated $5 to $24 per acre to the cost of soybean production in 2005. Growers or crop consultants now must scout for soybean aphids as a part of their routine crop management activities.

In this report, we summarize the research results that support the currently recommended economic threshold (ET). Soybean rust is another invasive, exotic pest that producers will need to manage in the future. These two pests usher in a new era in soybean IPM. *Integration* in soybean IPM must become the focal point of pest management programs. These exotic pests have permanently changed how soybean currently is managed in the north central states. Never again will soybean production be a relatively pest-free crop in North America.

## Soybean Aphid Damage Potential

In China and in other parts of Asia, soybean aphid is described as an occasional pest of soybean. Wang et al. (1996) demonstrated that when fields were colonized by soybean aphid during early vegetative growth, yield loss in excess of 50% occurred. In Minnesota, we have

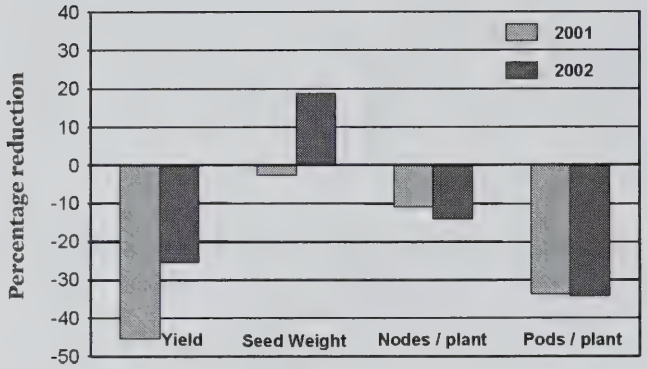



**Figure 1. Yield reductions caused by soybean aphid with a yield component analysis, 2001-2002.** (unpublished data by Ostlie and Ragsdale, University of Minnesota).

documented that yield loss caused by soybean aphid is primarily because of premature pod abscission (Figure 1). Flowering stages are most sensitive to aphid feeding, and high densities of soybean aphid during plant growth stages R1 through R4 (Fehr et al. 1971) can result in early pod abscission. If aphids are controlled after pods are lost, only a portion of the yield loss sustained by reduced pod set can be recovered through an increase in seed size. It is imperative to scout fields just before flowering and throughout the pod set period.

In this report, we focus on three main topics: 1) the current recommended ET and scouting methods to assess whether treatable populations exist, 2) the role biological control can play in permanently reducing soybean aphid populations, and 3) the interaction that fungicides used for soybean rust control have on soybean aphids and aphid-infecting fungi.

## Economic Thresholds and Scouting

Researchers throughout the north central states have collaborated over the past 5 years, resulting in a robust set of field experiments from which the economic injury level (EIL) and ET for soybean aphid were estimated. As with most newly introduced invasive pests, soybean aphid has yet to attain a stable population equilibrium. Soybean aphid will continue to adapt to conditions in North America, as will the community of natural enemies that will use soybean aphids as a food resource. Therefore, thresholds will need continued refinement as yield expectations, control costs, natural enemies, and soybean aphid population growth rates become better understood.

The current ET value is applicable over a wide range of yield and price expectations. The threshold was developed through research efforts associated with a North Central Soybean Research Program (NCSRP) grant, a grower-funded regional research program involving collaborators from nine midwestern states. The ET was calculated to be an average of 250 aphids per plant, with more than 80% of plants infested with aphids, and the ET is valid through growth stage R5 (beginning seed set). This threshold provides producers with a 7-day window during which treatment can occur before loss exceeds the cost of control. In the future, more dynamic thresholds will be developed to account for more variables, such as plant stage and aphid resistant or partially resistant varieties. Use of the current threshold should prevent a recurrence of the catastrophic losses observed in 2003, and as more data are collected, more refined thresholds that are more site-specific in their application will be developed.

In Minnesota, we have documented yield losses attributable to soybean aphid that approach 50%. During soybean aphid outbreaks, it is imperative that insecticides are applied in a timely manner, if a producer wants to avoid significant yield loss. A few days delay in application may result in massive yield loss. However, soybean aphid population growth rates have varied tremendously and are not consistent from year to year or even within years. Clearly, there is yet much to learn with regard to the factors that affect aphid population growth rates. On a regional scale, since 2000 there have been years during which aphid populations did not attain damaging levels or peak aphid abundance occurred much later in the growing season (during stage R6; full size seed in pods), greatly reducing the damage potential. Yield loss can still occur during late R5 and into R6, but the aphid densities that cause significant yield losses during these plant growth stages are substantially higher than the current ET. The exact ET value for late-season aphid infestation has not yet been defined.

### Materials and Methods

***Field plot design.*** In the NCSRP funded project, a common experimental approach was used by all participants. At each field site, a soybean variety adapted for that area was selected and planted within the normal range of planting dates for each location. Plots were four rows (30-inch spacing between rows) × 50 feet in length. Fallow ground surrounded each plot to facilitate treatment of individual plots with insecticide, to minimize spray drift among plots, and to encourage uniform aphid colonization throughout the experiment, because winged aphids are known to be attracted to

field edges (DiFonzo et al. 1996). Soybean aphids were allowed to naturally colonize the plots; however, aphids from a laboratory colony were distributed uniformly in the center two rows of each plot if aphids were not found colonizing plants by mid-vegetative growth (V5). Foliar insecticides were applied at predetermined aphid population levels. When the numbers of aphids reached the average target density, an insecticide was applied to all replicates of this treatment the following day. Each target aphid density (=treatment) was replicated a minimum of four times, and treatments were arranged in a completely randomized block design. If aphid populations started to rebound after the initial treatment, additional applications were made to prevent further aphid population development. Yield was estimated by harvesting the middle two rows and adjusting moisture to 13%. Maximum yield at each location was measured in replicated plots in which aphids were controlled throughout the season by repeated application of insecticide.

***Aphid sampling.*** Whole-plant samples were used to enumerate total number of aphids per plant. To detect small population densities early in the season, aphids on as many as 20 nonconsecutive plants were counted nondestructively in each plot. As the aphid population density and percentage of plants infested increased, the number of plants sampled was reduced to a minimum of five plants per plot when 100% of the plants were colonized. All data were converted to average number of aphids per plant to account for the varying number of plants sampled. Plant growth stage was noted each week so that aphid population density could be correlated with a particular plant growth stage. As a measure of seasonal aphid abundance, we calculated cumulative aphid-days (CAD) by using procedures outlined in Hanafi et al. (1989). Cumulative aphid-days represent the area under the aphid population curve and provide a single number that describes aphid density over the entire season.

## Results and Discussion

***Calculation of an EIL and ET.*** Five replicated field plots were used to calculate the initial yield-loss relationship between CAD and yield. The resulting linear regression equation (Figure 2) was used to estimate aphid density associated with yield loss. The first step in this process is to calculate a "gain threshold" for which the cost of control ($/acre) is expressed in bushels/acre. For example, if cost of control was $12/acre and soybeans were sold at $6.00/bu, the gain threshold would be 2 bu/acre. Because yield and price are variables that change, we express the gain threshold in terms percentage yield loss over a range of expected yield and price scenarios.

**Table 1. Yield loss (%) necessary to equal cost of control of soybean aphids**

| | Expected yield (bu/acre) | | |
|---|---|---|---|
| Price ($/bu) | 60 | 50 | 40 |
| $5.00 | 4.0 | 4.8 | 6.0 |
| $6.00 | 3.3 | 4.0 | 5.0 |
| $7.00 | 2.8 | 3.4 | 4.3 |

With five replicated field experiments used to calculate the yield loss relationship with CAD, we could not use actual yield to express this relationship, because yield potential among fields varied. We expressed all yield loss as a percentage yield loss relative to the aphid-free plots, i.e., the aphid-free treatment was assumed to represent the maximum potential yield for that location (100%). The relationship between CAD and percentage yield loss is shown in Figure 2. The EIL was calculated by setting control costs at $12.00 per acre, which includes the chemical cost and the cost of custom application (air). We then used a range of yield expectations and prices to develop a matrix of percentage yield loss that would equal the cost of control (Table 1). By substituting the percentage yield loss in Table 1 in the equation in Figure 2, we can express the EIL in terms of CAD required to suppress yield equal to the cost of control (Table 2).

To covert this EIL to an ET value that crop managers will assess in the field, we calculated the aphid density per plant that would occur 7 days before the densities reached the EIL. Our ET assumes that the initial aphid population was one aphid per plant. CAD that accumulate at densities less than one aphid per plant

**Table 2. EIL—yield loss caused by soybean aphid feeding equals the cost of control**

| | CAD | | |
|---|---|---|---|
| Price ($/bu) | 60 | 50 | 40 |
| $5.00 | 5,444 | 6,333 | 7,667 |
| $6.00 | 4,703 | 5,444 | 6,556 |
| $7.00 | 4,175 | 4,810 | 5,762 |

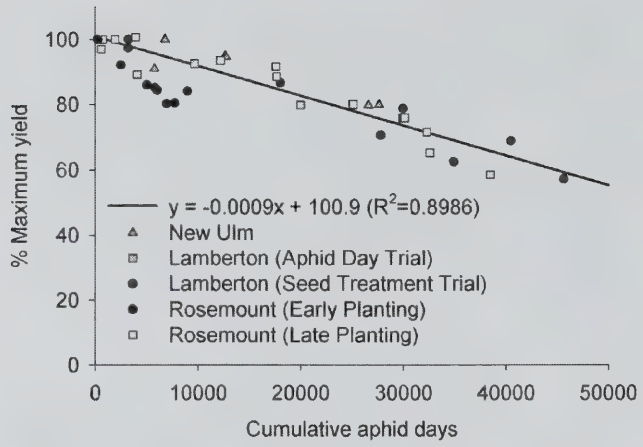



**Figure 2. Yield loss relationship in five separate field plots in Minnesota.**

are so small that we can disregard the CAD that occur before the density reaches a starting density of one aphid per plant. The 7-day lead time built into the ET makes two assumptions: 1) aphid population densities are increasing, and 2) a producer needs a minimum of 7 days to make arrangements for a field to be treated. The 7-day lead time also allows producers to reassess aphid population densities just before spraying to ensure that aphid numbers are still increasing and to account for inclement weather that precludes applying a foliar insecticide. To convert CAD to aphids per plant, we used a range of aphid growth rates. Population doubling times for soybean aphid have been estimated to be as small as 1.3 days in laboratory experiments for which temperature was held constant (McCornack et al. 2004). Population growth rates of soybean aphid observed in the field are lower, partly because of fluctuating temperatures, but also because natural enemies and plant quality act in tandem to reduce aphid population growth rates. The values used to calculate the ET represent actual population growth rates observed in field plots during aphid outbreaks.

The estimated numbers of aphids per plant when the EIL will be reached in 7 days are shown in Tables 3 and 4. The difference between the values in the two tables is that the population doubling time is either 2 days (Table 3) or 3 days (Table 4). We currently are collecting and analyzing data to improve our population growth rates estimates.

Data from field cages in which predators, parasites, and weather events, (e.g., pounding rain) are largely minimized or absent provide biased estimates of population growth rates. Estimates such as those developed in laboratory experiments are not appropriate to use

**Table 3. ET, expressed as aphids per plant, when aphid population doubling time is 2 days**

| | Aphids/plant | | |
|---|---|---|---|
| Price ($/bu) | 60 | 50 | 40 |
| $5.00 | 199 | 232 | 281 |
| $6.00 | 172 | 199 | 240 |
| $7.00 | 153 | 176 | 211 |
| Overall average | | **207** | |

**Table 4. ET, expressed as aphids per plant, when aphid population doubling time is 3 days**

| | Aphids/plant | | |
|---|---|---|---|
| Price ($/bu) | 60 | 50 | 40 |
| $5.00 | 281 | 323 | 396 |
| $6.00 | 243 | 281 | 338 |
| $7.00 | 215 | 248 | 297 |
| Overall average | | **291** | |

to calculate ET values. Tedious counting of aphids in replicated field plots, as well as evaluating the biotic and abiotic factors associated with aphid population growth rates, are needed to refine the current ET value. If aphid population growth rates are reduced substantially, whether by predators or by other natural enemies, there may be enough population regulation to prevent aphid densities from reaching the EIL. In Minnesota, this is exactly what we observed in several replicated field trials in 2005. Threshold densities were attained, but EIL densities were not attained; thus, treatment did not result in a yield benefit equal to the cost of control (Figure 3).

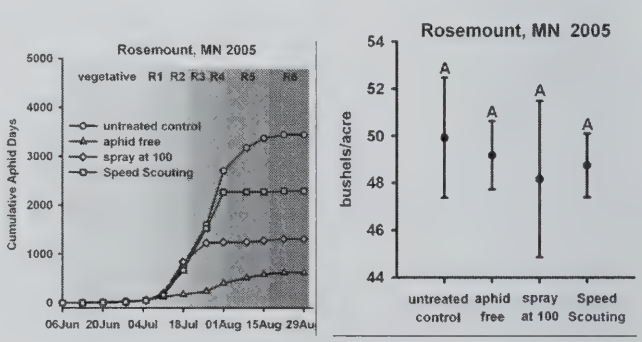



**Figure 3. CAD at Rosemount, MN 2005 and associated yield.**

A question might be why, with all of these variables, have we chosen to use a single ET value? The answer is entangled with the aphid population growth rate estimates. No matter which estimate of population growth rate is used (2- or 3-day doubling times), the difference between 153 (lowest price, lowest yield potential, slowest growth rate; Table 3) and 396 aphids per plant (highest price, highest yield potential, fastest aphid population growth rate; Table 4) is, at most, 2 days of reproduction. We chose to simplify the threshold by taking an average ET across all price, yield, and population growth rate estimates (Tables 3 and 4). The average is 249, and we rounded to 250 aphids per plant for the current ET. To improve this threshold requires better estimates of population doubling time. The caveat of 80% or more of the plants infested with aphids prevents treating an entire field when only a portion of the field may be infested, e.g., a hot spot within a single field.

The soybean aphid population growth rate is governed largely by weather (temperature and precipitation, density-independent mortality factors) and natural enemies (density-dependant mortality factors). To demonstrate how one factor, temperature, can drive aphid population growth rates, we have developed a simple model that runs with Microsoft Excel (Redmond, WA). The model is available at a University of Minnesota Web site, and it allows producers to use locally obtained forecasted weather data (daily minimum and maximum temperatures) to estimate soybean aphid density. The population growth rate used in this model is one for which aphid populations are growing in the absence of predation and without plant stress. The Soybean Aphid Growth Estimator (SAGE) model is strictly a temperature based population growth model. It provides an estimate of the aphid density that could be attained given ideal conditions (high plant quality and lack of natural enemies). Aphid population growth rate observed in the field will always be lower than this estimate. The model predicts the fewest number of days required for soybean aphid numbers to reach threshold densities. The difference one observes from this estimate and what is actually observed on a farm is the cumulative benefit of natural enemies, adverse weather events (other than temperature), and other factors, such as plant quality, that work in concert to slow soybean aphid population growth rates.

Soybean aphid growth estimator

| | Minimum Temperature °F | Maximum Temperature °F |
|---|---|---|
| Today | 58 | 78 |
| Tomorrow | 62 | 82 |
| 2 day | 77 | 97 |
| 3 day | 81 | 99 |
| 4 day | 74 | 89 |
| 5 day | 68 | 87 |
| 6 day | 66 | 89 |
| 7 day | 77 | 93 |
| Current density (aphids/plant) | | 35 |

| Estimated doubling time (days) | 2.4 Aphids/plant |
|---|---|
| Today | 35 |
| Tomorrow | 51 |
| 2 day | 71 |
| 3 day | 70 |
| 4 day | 84 |
| 5 day | 126 |
| 6 day | 187 |
| 7 day | 267 |
| Estimated days to threshold | 7 |

Your notes:

**Figure 4. Example of SAGE model, available at http://www.soybeans.umn.edu/crop/insects/aphid/aphid_sagemodel.htm.**

To download a copy of the SAGE model go to http://www.soybeans.umn.edu/crop/insects/aphid/aphid.htm and use the drop down box at the top of the page to get to the "SAGE model." As we learn more about how various factors affect population growth rate, this model will be updated and improved.

## Sampling Aphid Populations

Another commonly asked question is, "How can I spend less time sampling for soybean aphids? It just takes too long to count individual aphids on 30 plants per field." In response, we have developed a binomial sequential sampling program for soybean aphid and have termed this method as "Speed Scouting." Rather than count all of the aphids on a plant, a producer or consultant needs only to train his or her eyes to estimate how many aphids are present and to tally the number of plants that are infested with 40 or more aphids (Hodgson et al. 2004). The initial estimates were developed using only Minnesota data sets (86 data sets of weekly counts); but in 2005, entomologists across the region collaborated in a validation of Speed Scouting to determine whether a treatment decision recommended by Speed Scouting actually had aphid population densities greater than 250 aphids per plant. The advantages of Speed Scouting are most pronounced when aphid population densities are low (i.e., most plants have fewer than 40 aphids) or when aphid population densities are high (i.e., all plants have 40 or more aphids per plant). The use of Speed Scouting requires less time and fewer plants sampled to make a decision to treat or not to treat. Speed Scouting eliminates the need to count aphids at high densities, which is very time-consuming.

Speed Scouting is based on a mathematical relationship between actual aphid densities, and it is not a new ET. For example, when aphid densities are large, if the first 11 plants sampled have 40 or more aphids each, a scout can stop sampling and make a decision to treat the field within the next 7 days. Under these conditions, if one took the time to count aphids on a random sample of

30 plants, the average density would be greater than or equal to 250 aphids per plant.

Data sheets for Speed Scouting are available at http://www.soybeans.umn.edu/crop/insects/aphid/aphid_sampling.htm. The disadvantage of Speed Scouting is that to gain speed, one gives up precision. Preliminary analysis of the validation of Speed Scouting in 2005 showed that the results from Speed Scouting suggested that a treatment was necessary sooner than was justified by enumerative counts. In other words, Speed Scouting resulted in a more conservative decision, thus resulting in treating more often enumerative counts would have indicated (Figure 3). However, in Minnesota, the same could be said for enumerative counts across a broad array of experimental plots, because population growth rates in many locations in 2005 were lower than had been observed in previous years. In many replicated field plots, ET densities were reached, but aphid densities in untreated control plots never reached the EIL. In the future, it may be necessary to estimate how quickly populations are growing to prevent treating when no yield loss will occur.

## Biological Control

Long-term control of soybean aphid is the goal of a classical biological control program that is being pursued by a consortium of entomologists located at land-grant universities and USDA laboratories and with overseas collaborators. Classical biological control of soybean aphid entails finding natural enemies in the aphid's native range, determining the host range of these exotic insects when exposed to native aphids in North America, selecting strains or species that will be the most host-specific, and developing methods to release these insects. Biological control has been implemented successfully for a variety of exotic insect pests in the Great Plains, including cereal leaf beetle, alfalfa weevil, Russian wheat aphid, and European corn borer. Many of these biological control programs have reduced an exotic pest from major pest status to occasional pest status. The current research is lead by Dr. Bob O'Neil (Purdue University) through another NCSRP-funded project on the biological control of soybean aphid. The first release of an exotic natural enemy of the soybean aphid may occur in 2006, pending federal approval.

Teams of entomologists have brought back natural enemies from China, Korea, and Japan, where soybean aphid is an occasional pest. Biological control is not designed to eradicate the target pest but rather to suppress the population to levels below the ET. Clearly, the widespread use of insecticides is incompatible with biological control. Insecticides cannot discriminate between pests and beneficial insects. In IPM, the very foundation of biological control is reliance on natural enemies first and use of insecticides only when natural enemies fail to keep the pest population density below the ET. By applying insecticide only when population densities exceed the ET, we take full advantage of the natural enemies already present. It has long been observed that biological control is far more successful in low-value crops for which insecticide use often is not justified or in perennial cropping systems in which insecticides are used sparingly in successive years. The cropping practices least compatible with biological control are annual cropping systems in which much of the acreage is treated each year. Only by carefully *integrating* the use of ETs into soybean pest management decisions will biological control reach its full potential.

## Interaction of Aphid Populations with Fungicides

In 2005, we began a study to evaluate the potential interaction between fungicides and the impact these materials have on a group of little known natural enemies—entomopathogenic fungi. In previous research conducted in Minnesota on potato IPM, there was a clear detrimental effect on these insect-infecting fungi when plots were repeatedly treated with fungicide. As a result, green peach aphid populations in potato increased to extremely high densities because of the suppression of these insect pathogens (Ruano-Rossil et al. 2002).

In 2005, we initiated a 2-year study to evaluate what effect fungicides used for control of soybean rust might have on the fungal pathogens that infect soybean aphid. Fungicides were applied with ground equipment that delivered 27.1 gal/acre of spray volume, and recommended rates of fungicide were applied. At Rosemount, MN (Figure 5), fungicides caused no direct toxicity to soybean aphids. In contrast, at Lamberton, MN (Figure 6), one fungicide treatment seemed to significantly reduce soybean aphid density. However, the reduction was not consistent across all plots treated with this fungicide or in equivalent treatments that had a third fungicide applied in late August.

Mortality of soybean aphids caused by entomopathogenic fungi at Rosemount never exceeded 5%, even in the untreated control (Figure 5). As with plant pathogenic fungi, it takes three interacting factors to result in an

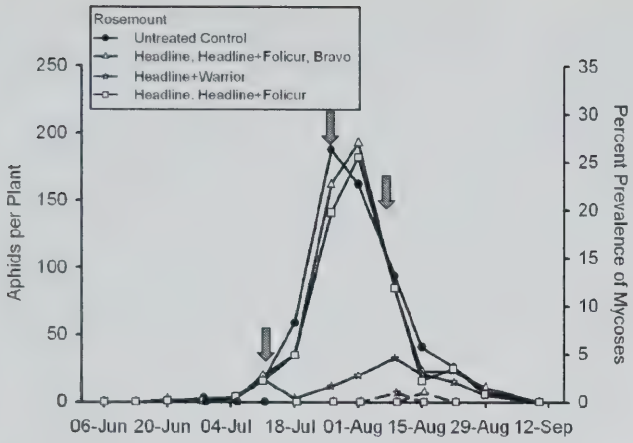



**Figure 5. Soybean aphid density in plots treated with fungicide, Rosemount, MN, 2005.** Application dates are indicated with down arrows (7/13, 7/27, and 8/11). Dashed lines indicate prevalence of fungal-infected aphids. (Koch and Ragsdale, unpublished, 2005).

active infection by insect pathogenic fungi—inoculum, susceptible hosts, and a permissive environment. Both inoculum and aphids were present at Rosemount, but the environmental conditions at Rosemount were not conducive for disease development. It was hot and dry, and relative humidity was generally too low to allow for infection to occur. Entomopathogenic fungi require several hours of humidity above 95% for sporulation to occur, and the predominant aphid-infecting fungus isolated from soybean aphid, *Pandora neoaphidis*, grows best at relatively cool temperatures. It is interesting to note that spider mites also are kept under control through the action of another entomopathogenic fungus, *Neozygites floridana*. When temperatures are hot and relative humidity is low, the environmental conditions are not conducive for this fungus to sporulate and infect spider mites. Consequently, twospotted spider mite populations are always associated with drought conditions in the upper Midwest. Another intriguing question that should be asked is, What, if any, impact will fungicides have on spider mite populations?"

In contrast with the Rosemount data, all conditions were favorable for fungal infection to occur at Lamberton late in the growing season when aphid populations were at peak density. At Lamberton, fungicides suppressed prevalence of fungal-infected aphids by more than 90% (Figure 6). However, fungicides did not cause an increase in peak aphid density as we have observed in potato production systems (Ruano-Rossil et al. 2002). Recent work at Cornell University (Nielsen and Hajek 2005) showed that prevalence of fungal-infected soybean aphid was greatest when soybean aphid was collected from its overwintering host, buckthorn, *Rhamnus cathartica*. This relationship is partly because environmental conditions conducive for fungal infection are prone to occur late in the growing season. During late August in Minnesota, dew point is often reached overnight and nighttime temperatures are lower.

Overall, fungicides in the first year of this study had little impact on peak aphid density, but fungicides did result in a lower proportion of fungal-infected aphids at a time of the season when aphids are leaving soybean and returning to buckthorn. From these preliminary data, we would hypothesize that fungicide use on soybean might result in fewer fungal-infected aphids on buckthorn. Consequently, a higher survival rate of soybean aphids on buckthorn will result in more overwintering eggs to be deposited on buckthorn. If winter temperatures do not drop below the lower lethal point of –29°F (McCornack et al. 2005) and permit successful overwintering, the result might be higher colonization rates in soybean the following spring.

It remains to be seen whether widespread use of fungicides in the north central states will affect winter

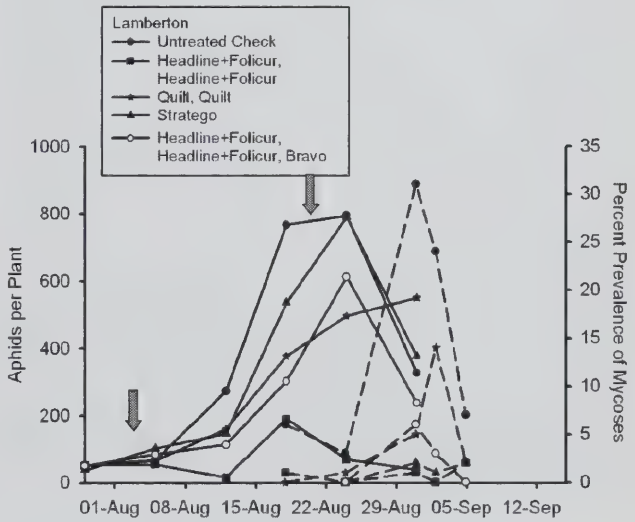



**Figure 6. Solid lines indicate aphid density in plots treated with fungicide at Lamberton, MN, 2005.** Applications were made on 22 July; 5 Aug., and 19 Aug. for the first, second, or third application as indicated in the legend. Dashed lines indicate prevalence of fungal-infected aphids. Down arrows indicate approximate date of the last two fungicide applications. (Koch, Ragsdale, and Potter, unpublished, 2005).

survival of soybean aphid. The potential exists, and this research is an example of how crop protection products can have unintended consequences. We are just beginning to unravel the relationships that exist among soybean aphids, entomopathogenic fungi, and fungicides used for soybean rust control.

## Conclusion

Soybean IPM is at a crossroads. With new and unpredictable exotic pests present in North America, soybean production has permanently changed. The challenge for researchers is to continue to investigate the possible interactions and solutions for these unintended consequences. It is incumbent upon producers to use pesticides only to prevent predictable yield losses. IPM was developed to take advantage of all the biotic and abiotic factors that reduce pest populations, with the caveat that pesticides should be used only when natural controls fail to keep pest populations in check. In the short term, insecticides may be necessary to avoid catastrophic losses caused by soybean aphids and fungicides may be needed to prevent losses caused by Asian soybean rust. What must be avoided is the use of pesticides as cheap insurance. If there is not a target pest to treat or if pest density is below an established ET, there is no reason to treat. There simply are too many consequences of using broad-spectrum pesticides if their use is not economically justified. Unnecessary use of pesticides not only increases production costs without any economic return but also may severely disrupt biological and natural control agents, affecting populations during a given growing season, and possibly having longer term effects.

## References


Blackman, R. L., and V. F. Eastop. 2000. Aphids on the world's crops: an identification and information guide, 2nd ed. Wiley, Chitchester, United Kingdom.

Clark, A. J., and K. L. Perry. 2002. Transmissibility of field isolates of soybean viruses by *Aphis glycines*. Plant Disease 86: 1219–1222.

Davis, J. A., E. B. Radcliffe, and D. W. Ragsdale. 2005. Soybean aphid, *Aphis glycines* Matsumura, a new vector of *Potato Virus Y* in potato. American Journal of Potato Research 81: 101–105.

DiFonzo, C. D, D. W. Ragsdale, E. B. Radcliffe, N. C. Gudmestad, and G. A. Secor . 1996. Crop borders reduce potato virus Y incidence in seed potato. Annals of Applied Biology 129: 289–302.

Fehr, W. R., C. E. Caviness, D. T. Burmood, and J. S. Pennington. 1971. Stage of development descriptions for soybeans, *Glycines max* L. (Merrill). Crop Science 11: 929–931.

Hanafi, A., E. B. Radcliffe, and D. W. Ragsdale. 1989. Spread and control of potato leafroll virus in Minnesota. Journal of Economic Entomology 82: 1201–1206.

Hodgson, E. W., E. C. Burkness, W. D. Hutchison, and D. W. Ragsdale. 2004. Enumerative and binomial sequential sampling plans for soybean aphid (Homoptera: Aphididae) in soybean. Journal of Economic Entomology 97: 2127–2136.

McCornack, B. P., D. W. Ragsdale, and R. C. Venette. 2004. Demography of soybean aphid (Homoptera: Aphididae) at summer temperatures. Journal of Economic Entomology 97: 854–861.

McCornack, B. P., M. A. Carrillo, R. C. Venette, and D. W. Ragsdale. 2005. Physiological constraints to the overwintering distribution of the soybean aphid (Homoptera: Aphididae). Environmental Entomology 34: 235–240.

Nielsen, C., and A. E. Hajek. 2005. Control of invasive soybean aphid, *Aphis glycines* (Hemiptera: Aphididae), populations by existing natural enemies in New York state, with emphasis on entomopathogenic fungi. Environmental Entomology 34: 1036–1047.

Ruano-Rossil, J. M., E. B. Radcliffe, and D. W. Ragsdale. 2002. Disruption of entomopathogenic fungi of green peach aphid, *Myzus persicae* (Sulzer), by fungicides used to control potato late blight, pp. 365–370. *In* Dedryver et al. [eds.], Aphids in a New Millenium, 6th International Symposium. INRA, Versailles.

Wang, S., X. Bao, Y. Sun, R. Chen, and B. Zhai. 1996. Study on the effect of population dynamics of soybean aphid (*Aphis glycines*) on both growth and yield of soybean. Soybean Science (China) 15: 243–247.

# Is an Airplane a Point Source?

Dee Ann Staats

Both the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and the Federal Water Pollution Control Act, or "Clean Water Act" (CWA), were enacted in 1972 and have coexisted harmoniously in the regulatory arena for nearly 30 years. However, decisions in four recent federal court cases spanning two circuits have strained this relationship by muddying interpretation and overlapping enforcement of these two laws, such that CWA now is superseding FIFRA in some states. The "outfall" of this litigious quagmire flows surreptitiously into society, affecting a wide expanse of parties, including growers, applicators, state regulators, and permit writers, local municipalities, and vector control bodies, which ultimately may negatively affect public health. The costs of spraying pesticides have increased due to permit and legal fees, the response time for vector control has increased, and ultimately the price will be paid by the consumer and tax payer. Four years after the first case, legislation has been introduced in the U.S. House of Representatives to disentangle the legal ropes and return to the sanity of the law's original intent. Meanwhile, stakeholders wait and the nation's health and food supply hang in the balance.

## Laws

FIFRA regulates the licensing, distribution, sale, and labeling of pesticides. It is designed to protect human health and the environment from "unreasonable adverse effects" (FIFRA 1972). The Environmental Protection Agency (EPA) and FIFRA require that pesticides undergo an extensive testing and review process to become "registered." Restrictions regarding the use and application of the pesticide are listed on the label; therefore, the label is the law. FIFRA provides civil and criminal penalties for violations of label requirements.

The CWA was intended to restore and maintain the chemical, physical, and biological integrity of the nation's waters. Specifically, the law applies to discharges from a "point source," which is defined as "a discrete conveyance such as a pipe, ditch, container, vessel, or other floating craft" (CWA 1972). Could an airplane be considered a "floating craft," and a spraying nozzle on that airplane considered "a discrete conveyance?"

The CWA defines a "pollutant" as "dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt and industrial, municipal, and agricultural waste discharge into water" (CWA 1972). The key aspect to bear in mind is that a "pollutant" is defined as a "waste," not the presence of a chemical during its intended and regulatory-approved use. The CWA requires National Pollutant Discharge Elimination System (NPDES) permits for any entity that emits a pollutant into the waters of the United States. Another important caveat is that FIFRA does not provide for citizen suits; however, such suits are allowed under the CWA.

## Court Decisions

### Headwaters, Inc. v. Talent Irrigation District (2001)

An environmental group sued a municipal corporation that operates a system of irrigation canals in Oregon,

alleging that they (the municipal corporation) had violated the CWA by not obtaining an NPDES permit to spray an aquatic herbicide to kill weeds and algae in drainage ditches, even though they were applying a FIFRA-registered product. At question was whether the application of a pesticide to water constitutes a "discharge of a pollutant." Both the lower court and the Ninth Circuit Court of Appeals agreed that the pesticide was a pollutant under the CWA and that an irrigation canal is a navigable water of the United States. However, the appellate court disagreed with the lower court's finding that an NPDES permit was not required because the product was properly regulated by FIFRA and had an EPA-approved FIFRA label. The higher court found that FIFRA and CWA have different purposes, and that neither controls the other; and having a FIFRA-approved label does not obviate the need to obtain an NPDES permit because the FIFRA label is nationwide and does not account for location-specific requirements, whereas the CWA considers local environmental conditions. Therefore, NPDES permitting is required when applying pesticides to navigable waters of the U.S. The higher court reversed the district court's grant of summary judgment in favor of the defendants.

### League of Wilderness Defenders/Blue Mountains Biodiversity Project v. Forsgren (2002)

Environmentalist groups filed a lawsuit alleging that the U.S. Forest Service violated the CWA in its annual spraying over national forest lands in Oregon and Washington by not acquiring an NPDES permit and that the Environmental Impact Statement (EIS) was inadequately prepared. The District Court issued a summary judgment in favor of the Forest Service, accepting their argument that aerial spraying of pesticides is a non-point source water pollutant, which does not require an NPDES permit. However, the appellate court reversed this decision and ruled that insecticides meet the CWA definition of pollutant and that the aircraft equipped with a spraying apparatus constituted a point source. Therefore, the Forest Service was prohibited from spraying pesticides until they obtained an NPDES and completed a revised EIS.

### Altman v. Town of Amherst, N.Y. (2002)

Several residents of Amherst, NY, alleged that the town violated CWA by spraying pesticides for mosquito control in wetland areas without an NPDES permit, claiming that the spray equipment was a point source and that the wetlands are navigable waters of the U.S. The lower court granted the defendant's motion to dismiss stating that spray drift is not a chemical waste under the CWA and that pesticide use was best regulated under FIFRA. However, the appellate court found that the lower court had limited discovery, and notably invited the EPA to offer its views on the policy and legal questions. The EPA filed a motion to dismiss that was later granted by the Second Circuit in 2004.

### No Spray Coalition v. City of New York (2003)

A citizens group alleged that the City violated CWA NPDES permit requirements through the aerial and ground spraying for mosquitoes, which plaintiffs claimed constituted a discharge of a pollutant under CWA, even though the pesticide was FIFRA-approved. The lower court found that the FIFRA provisions disallowing citizen suits prevailed over CWA's allowance of such suits. But, the appellate court reversed the lower court's decision, holding that a citizen suit under the CWA may be brought regardless of whether the action is regulated under FIFRA, and remanded the case back to the District Court in 2004. The District Court then deferred to the EPA Pesticides/NPDES Policy Guidance (refer to "EPA's Regulatory Responses" in this paper), stating if a pesticide is applied according to its label, then an NPDES permit is not required.

## States Affected

The Second Circuit encompasses three states—Connecticut, New York, and Vermont. Eleven states/territories are included in the Ninth Circuit—California, Oregon, Washington, Arizona, Montana, Idaho, Nevada, Alaska, Hawaii, Guam, and the Northern Mariana Islands. In response to the Ninth Circuit decisions, water quality rules were amended to require NPDES permits for pesticide applicators in both California and Washington. Rather than mandating permits, Oregon suggested that applicators obtain state-issued permits to protect against litigation.

## Outfall

Scott Campbell, chairman of the National Water Resources Association, Inc., and an attorney specializing in clean water law, testified before a U.S. House of Representatives subcommittee on September 29, 2005 that "Agriculture has been dramatically impacted in states within the Ninth Circuit because of these

decisions. Effective delivery of water requires periodic treatment of surface water canals and ditches to reduce growth of moss and other aquatic plants. Common sense suggests that wise use of beneficial chemical products, in accordance with the label restrictions previously adopted by EPA, is more than adequate to protect the environment and allow the human population to obtain the benefits of theses pest control substances."

Blueberry farmers in Maine have been threatened with lawsuits alleging NPDES/CWA violations for aerial spraying near water bodies. In response to this intimidation, the farmers ceased aerial spraying and instead relied on ground spraying to avoid legal action. Edward Flanagan, president and CEO of Maine-based blueberry growers Jasper Wyman & Son, testified on behalf of the American Farm Bureau Federation at the same hearing as Campbell. He stated that farmers apply for NPDES permits from state and county governments, but they are informed by the regulators that such permits are not required to spray pesticides. Flanagan continued, "By filing a citizen suit under the CWA, the activists could have their legal expenses paid by Wyman's, if they prevailed. However, if Wyman's prevailed in the lawsuit, we could not pursue reimbursement for our legal expenses from the plaintiffs. In order to avoid a drawn out, costly lawsuit, our only option is to give in and get an NPDES permit that the state of Maine and EPA say we don't need."

## EPA's Regulatory Responses

### 2003 Interim Statement and Guidance

In July 2003, the EPA issued an Interim Statement & Guidance memorandum stating that chemical pesticides are not wastes, and therefore not pollutants, because they are "EPA-evaluated products designed, purchased and applied to perform their intended purpose of controlling target organisms in the environment." The EPA does not believe that biological pesticides (i.e., products derived from plants, fungi, bacteria, or other nonhuman synthesis and that can be used for pest control that usually do not have toxic effects on animals and people, compared with many chemical pesticides) are pollutants. The application of pesticides either directly in U.S. waters or aerially above or near waters to control pests does not require a CWA permit, so long as the use is done in compliance with relevant FIFRA requirements. Pesticides applied in a manner consistent with FIFRA do not constitute either chemical wastes or biological materials as defined by CWA. The EPA used as a rationale the fact that this policy is consistent with more than 30 years of CWA administration and that pesticides used in violation of FIFRA are subject to all relevant statutes, including the CWA.

### 2003 Legal Memorandum

In September 2003, the EPA General Counsel issued a legal memorandum to EPA region nine officials stating that the EPA disagreed with the Forsgren Decision and that outside the Ninth Circuit, the EPA would continue its long-standing interpretation of FIFRA and CWA that the lawful application of a registered pesticide in accordance with its label does not constitute pollution or require an NPDES permit. They also indicated that within the Ninth Circuit, the EPA would not acquiesce to the ruling for materials other than pesticides, or when pesticides are not applied directly over and into U.S. waters.

### 2005 Policy Statement

On January 28, 2005, the EPA issued a policy statement as follows: "It has been and will continue to be the operating approach of the Agency that the application of agricultural and other pesticides in accordance with label directions is not subject to NPDES permitting requirements."

## Proposed Legislation

In April 2005, Rep. Butch Otter (R-Idaho) and Rep. Dennis Cardoza (D-California) introduced the "Pest Management and Fire Suppression Flexibility Act" H.R. 1749. The bill would amend the CWA to clearly specify that NPDES permits are not required to apply pesticides near or around standing water or water supply sources.

## CropLife America's Policy

CropLife America supports the EPA's efforts to bring clarity and uniformity to this issue, and suggests that the Agency codify through formal rulemaking its long-standing position on NPDES permits and pesticide usage consistent with its Interpretive Statement issued on January 28, 2005, and Guidance issued in July 2003. CropLife America supports the efforts of Rep. Otter and Rep. Cardoza and the "Pest Management and Fire Suppression Flexibility Act."

## So, Is an Airplane a Point Source?

No. According to the EPA, a registered pesticide is not a pollutant when it is applied in accordance with

its FIFRA label; therefore, the airplane applying said pesticide would not be a point source or even a non-point source.

## References


Abate, R.S. and M.T. Stanger. 2005. Pesticides and water don't mix: addressing the need to close a regulatory gap between FIFRA and the CWA, Environmental Law Reporter News & Analysis, January 2005, p. 10055.

Altman v. Town of Amherst, N.Y., 47 Fed. Appx. 62 (2d Cir. 2002).

Copeland, C. 2005. Pesticide use and water quality: Are the laws complementary or in conflict?" Congressional Research Service Report for Congress, June 2, 2005 (www.ncseonline.org/NLE/CRS).

Dinnage, R.J. 2005. Bill altering rules for pesticide use over water goes before House. Pesticide & Toxic Chemical News, October 3, 2005.

Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). 1972. 7 U.S.C. §§ 136–136y.

Federal Water Pollution Control Act (CWA). 1972. 33 U.S.C. §§ 1251–1387.

Headwaters, Inc. v. Talent Irrigation District, 243 F.3d 526 (9th Cir. 2001).

League of Wilderness Defenders/Blue Mountains Biodiversity Project v. Forsgren, 309 F.3d 1181 (9th Cir. 2002), cert. denied).

No Spray Coalition v. City of New York, 351 F.3d 602 (2d Cir. 2003).

U.S. Environmental Protection Agency. 2003. Interim statement and guidance on application of pesticides to waters of the United States in compliance with FIFRA. 68 Federal Register 48385, Aug. 13, 2003.

U.S. Environmental Protection Agency. 2005. Application of pesticides to waters of the United States in compliance with FIFRA, proposed rulemaking and notice of interpretive statement. 70 Federal Register 5093, Feb. 1, 2005.

# Hazards, Hazards Everywhere; But Is There Any Risk?

ALLAN S. FELSOT

Hardly a day goes by without a news headline screaming danger to our health and environment. For most citizens, life goes on as they struggle to just make a living, stoically accepting the bad news as one more inevitable sign of global destruction or skeptically dismissing it as howls of "crying wolf." Technology increasingly beyond our personal control exists discordantly with a facile accessibility to information and regulatory transparency unparalleled in human culture. But can we Google our way to understanding? Is what we see (or find) any help in interpreting (or predicting) what is really happening out there, in that space we deferentially call the environment yet treat abstractly as if independent of its fabric?

Such questions may be more important than ever before as resources for "fixing problems" become ever scarcer and must compete among the policy prerogatives of the new administrators our democracy recycles in every few years. Every administration is criticized for not doing enough, or alternatively, for wasting too much money on "phantom" problems. Surely there must be a rational way to allocate our management resources.

I propose that any attempt to be rational about protecting anything must separate the concepts of hazard and risk. The National Research Council (NRC), an arm of the National Academy of Sciences, has defined hazard as, "An act or phenomenon posing potential harm to some person(s) or thing(s); the magnitude of the hazard is the amount of harm that might result, including the seriousness and the number of people exposed" (NRC 1989). A report by the International Program on Chemical Safety/Organization for Economic Cooperation and Development (IPCS/OECD) Working Party, has offered the following definition for hazard: "inherent property of an agent or situation capable of having adverse effects on something" (Duffus 2001). One could find many similar definitions for hazard by a casual search on the Internet, but all simplify to the concept of any technology or event possessing potential harm. This definition applies well to our chemical technologies, and arguably pesticides are the epitome of a technology for which hazards are a given.

But, should the knowledge that a substance is hazardous, i.e., potentially harmful, precipitate a corresponding (and immediate) reaction to do something about it? We are precautious by nature and thus want to be careful when we have knowledge of potential harm. The problem is knowing the appropriate amount of resources (both time and money) to expend on potential harm.

To help us allocate appropriate attention to a hazard, we must understand the concept of risk. The NRC (1989) defined risk as "adds to the hazard and its magnitude the probability that the potential harm or undesirable consequences will be realized." The IPCS/OECD (Duffus 2001) defined risk as "the probability of adverse effects caused under specified circumstances by an agent in an organism, a population, or an ecological system." Thus, all definitions of risk simplify to the concept of likelihood or probability that something bad will happen. Importantly, however, the probability of the hazard manifesting itself (i.e., becoming more than just potential harm) is situational or conditional.

To help determine appropriate management for the myriad of hazards, our regulatory agencies (as well as forward looking businesses) use the risk assessment process. About 20 years ago, the National Academy of

Sciences supported the risk assessment strategy as a logical process for helping make decisions about the safety of chemical technologies to humans (NRC 1983). This process was further discussed in the context of air pollution and human health (NRC 1994). The basic risk assessment process had also been extended to nontarget organisms and ecological systems (NRC 1993). The Environmental Protection Agency (EPA) (EPA 1998, 2004) has issued theoretical and practical guidelines for conducting ecological risk assessments.

## Overview of Risk Assessment As Applied to Pesticide Technology and Ecological Risk

As applied to pesticide technologies, risk assessment is the determination of the potential hazards of a substance and the likelihood those hazards might occur under the legally designated use conditions of that substance. In this context, the distinction between hazard and risk is pertinent to understanding when and why it may be possible to use a pesticide without incurring unintended harm to nontarget organisms. Conversely, distinguishing between hazard and risk may inform us as to when uncertainty about harm, efficacy, or both dictates inordinate precaution or immediate action in decisions about whether to use or register a pesticide.

It is widely recognized, as well as observed through repeated experimentation, that natural and synthetic substances at one dose may have no adverse effects on an organism, but at another higher dose can cause harm. This concept, frequently called "dose makes the poison", is the fundamental principle guiding toxicological studies, and it is discussed in all basic toxicology textbooks. Of course, the popular phrase dose makes the poison belies more complex interactions between a substance and its effects on an organism. The dose required to cause deleterious effects within a population of organisms can vary depending on the route of exposure (oral, dermal, or inhalational) to the substance, the length of time over which it is administered (acute versus chronic), and the age, sex, and health of an organism. Nevertheless, the appearance or magnitude of an effect of any substance is tied to its dose. Hazard, therefore, can be thought of as a substance's dose-related array of possible deleterious effects on an organism of a specific age, gender, and health status exposed via oral, dermal, and inhalational pathways.

Risk is the probability or likelihood that the array of known hazards of a substance will actually occur if or when an organism is exposed. If exposure is nonexistent, then the likelihood of an effect is nil. If exposure does occur, then the likelihood of the substance being a hazard is conditioned not only on the dose but also on the age, gender, and health of that organism as well as the specific route of exposure. The important point is that the risk of adverse effects after exposure to a substance may be very low or high depending on all the factors affecting the hazards of that substance.

The goal of risk assessment is to characterize the likelihood of harm given a certain exposure level under the specific conditions of use. Four steps are used to collect and assemble data so that the likelihood of harm can be characterized either qualitatively or quantitatively. The four steps—hazard identification, dose–response assessment, exposure assessment, risk characterization—were formally described by the National Academy of Sciences (NRC 1983) for human health protection and extended to ecological risk assessment (NRC 1993). Federal and State regulatory agencies use these four steps to gather and analyze data about pesticides, industrial chemicals, and chemical contaminants in the environment in accordance with their legislative mandates to protect human health and the environment. In short, risk assessment is a process of gathering, analyzing, and characterizing the significance of data about hazards of chemicals. These activities are carried out as scientific experiments in which hypotheses are tested through observation. Ideally, information generated from risk assessment provides guidance to risk management decisions, but risk management necessarily provides feedback to direct the risk assessment process (NRC 1993). Furthermore, risk management determines the significance of the results emanating from risk characterization. In short, risk management sets standards for tolerable risks and formulates decisions to mitigate unacceptable risks.

### Ecological Hazard Identification in Current Regulatory Practice

For purposes of ecological risk assessment, hazard identification is "the determination of whether a particular hazardous agent is associated with health or ecological effects that are of sufficient importance to warrant further scientific study or immediate management action" (NRC 1993). Given the basic axiom of dose makes the poison, all substances are potential hazards, so all candidate pesticidal substances under consideration for registration must have some test data indicating the nature of their hazard. The EPA

(2005) has developed a set of required test guidelines that address ecological hazards. More than 40 different tests must be submitted to the EPA before consideration of pesticide registration (Table 1). The organisms tested include soil microorganisms, algae, aquatic and terrestrial vascular plants, invertebrates, and vertebrates.

Tests for hazard identification cover acute and chronic exposure periods. For aquatic organisms, acute toxicity testing requires continuous exposures over periods of 48 to 96 hours, but for terrestrial organisms, such as birds, a single forced oral exposure would be used. The toxicological endpoint (i.e., the hazard being measured) is mortality—how many organisms die during and after the exposure period.

Testing of aquatic organisms for chronic effects follows test animals through a complete life cycle to examine not only obvious illness and survival but also developmental and reproductive success. The length of the test depends on the test animal's life cycle. For terrestrial organisms, exposure is through food ingestion, and the animal is followed through the reproductive part of its life cycle.

## Dose (Exposure)–Response Assessment

Dose– or exposure–response assessment is the determination of the relationship between the magnitude of exposure and the occurrence of the adverse effects delineated by hazard identification. For purposes of obtaining a pesticide registration, hazard identification and dose–response assessment are linked because the toxicological endpoints of concern have been simplified to either mortality or developmental or reproductive effects.

Dose is the amount of chemical that is absorbed or deposited into the body of an organism after exposure. For terrestrial organisms, dose can be expressed as the milligrams per body weight (mg/kg) or as the concentration in the food (also expressed as milligrams per kilogram, which is a part per million, ppm). The toxicity data from the rodent studies required in human health assessments are used as a surrogate for terrestrial nontarget mammals. Various bird species are typically tested by either forcing known amounts of toxicant directly down their gullet, or by mixing the toxicant in their food.

For aquatic organisms, the concentration of pesticide in water, expressed as micrograms (×g) per unit volume (liter, L), i.e., a part per billion (ppb), is used, rather than the dose. The actual amount of pesticide absorbed by an aquatic organism (and thus the dose) is not usually measured. Thus, the relationship between body residue and death is not typically used in ecological risk assessment.

Animal acute toxicity studies yield estimates of the dose or concentration necessary to kill 50% of the tested animals (expressed as the $LD_{50}$ or $LC_{50}$). Animal chronic toxicity tests seek a dose or concentration that causes no observable adverse effect (expressed as the NOAEL or NOAEC) on development or reproduction. Plant toxicity tests seek the concentration in soil that reduces germination or growth by 25% (expressed as the GR25).

Although prospective pesticide registrants must submit to the EPA data from hazard identification and exposure-response assessment, the agency will also examine acute and chronic toxicity tests that have been published in the peer-reviewed literature. From this array of data (i.e., generated by industry and institutional research facilities), the EPA will choose the most sensitive plant, aquatic invertebrate, fish, and bird based on a comparison of the $LD_{50}/LC_{50}$ and NOAEL/NOAEC. The most sensitive toxicological (or hazard) endpoint thus becomes the benchmark for determining the risk of adverse effects.

## Exposure Assessment

Exposure assessment can be defined as the determination of the extent of exposure to a pesticide before or after application as directed by the product label and ideally as recommended by good agricultural practices. For registration of new chemicals, the exposure scenario would represent the conditions attendant to how the chemical would be marketed. For older chemicals, exposure could be modified by changes in regulatory requirements as reflected on the product label.

The EPA typically uses models to generate exposure information. For assessment of pesticide exposure to terrestrial vertebrates, the EPA assumes direct overspray on foliage, seeds, fruits, and insect prey. Based on an updated database known as the Kenaga nomogram, and making adjustments for per-acre application rates, the EPA chooses the residue concentration (expressed as ppm) that the subject test organisms could be exposed to (Fletcher et al. 1994). Thus, the EPA is estimating exposure to terrestrial animals encountered either within fields and orchards or directly at their edges. Within this context, the EPA has to make assumptions

**Table 1. Hazard identification tests required for ecological risk assessment of pesticides (EPA 2005)**

| Guideline no. | Title of test | Guideline no. | Title of test |
|---|---|---|---|
| 850.1000 | Special considerations for conducting aquatic lab studies | 850.2400 | Wild mammal acute toxicity |
| 850.1010 | Aquatic invertebrate acute toxicity test, freshwater daphnids | 850.2450 | Terrestrial (soil-core) microcosm test |
| 850.1020 | Gammarid acute toxicity test | 850.2500 | Field testing for terrestrial wildlife |
| 850.1025 | Oyster acute toxicity test (shell deposition) | 850.3020 | Honey bee acute contact toxicity |
| 850.1035 | Mysid acute toxicity test | 850.3030 | Honey bee toxicity of residues on foliage |
| 850.1045 | Penaeid acute toxicity test | 850.3040 | Field testing for pollinators |
| 850.1055 | Bivalve acute toxicity test (embryo larval) | 850.4000 | Background-nontarget plant testing |
| 850.1075 | Fish acute toxicity test, freshwater and marine | 850.4025 | Target area phytotoxicity |
| 850.1085 | Fish acute toxicity mitigated by humic acid | 850.4100 | Terrestrial plant toxicity, Tier I[1] (seedling emergence) |
| 850.1300 | Daphnid chronic toxicity test | 850.4150 | Terrestrial plant toxicity, Tier I[1] (vegetative vigor) |
| 850.1350 test | Mysid chronic toxicity test | 850.4200 | Seed germination/root elongation toxicity |
| 850.1400 | Fish early-life stage toxicity test | 850.4225 | Seedling emergence, Tier II[1] |
| 850.1500 | Fish life cycle toxicity | 850.4230 | Early seedling growth toxicity test |
| 850.1710 | Oyster BCF[2] | 850.4250 | Vegetative vigor, Tier II[1] |
| 850.1730 | Fish BCF[2] | 850.4300 | Terrestrial plants field study, Tier III[1] |
| 850.1735 | Whole sediment acute toxicity invertebrates, freshwater | 850.4400 | Aquatic plant toxicity test using *Lemna* spp. Tiers I and II[1] |
| 850.1740 | Whole sediment acute toxicity invertebrates, marine | 850.4450 | Aquatic plants field study, Tier III[1] |
| 850.1790 | Chironomid sediment toxicity test | 850.4600 | *Rhizobium*–legume toxicity |
| 850.1800 | Tadpole/sediment subchronic toxicity test | 850.4800 | Plant uptake and translocation test |
| 850.1850 | Aquatic food chain transfer | 850.5100 | Soil microbial community toxicity test |
| 850.1900 | Generic freshwater microcosm test, laboratory | 850.5400 | Algal toxicity, Tiers I and II[1] |
| 850.1950 | Field testing for aquatic organisms | 850.6200 | Earthworm subchronic toxicity test |
| 850.2100 | Avian acute oral toxicity test | 850.6800 | Modified activated sludge, respiration inhibition test for sparingly soluble chemicals |
| 850.2200 | Avian dietary toxicity test | 850.7100 | Independent laboratory validation |
| 850.2300 | Avian reproduction test | | |

[1] Risk assessment is conducted through a system of tiered tests that move from screening with a few simple experimental variables (Tier I) to more complex situations that reflect environmental reality (Tiers II and III).

[2] BCF = Bioconcentration Factor (a measure of the tendency to accumulate chemicals from the environment).

about the amount of food eaten by birds or rodents per unit area of habitat.

For assessment of exposure in aquatic habitats, the EPA uses a screening model called GENEEC and a more sophisticated model called PRZM to generate residue data translocating from a field in runoff and erosion. Spray drift is typically set as a fixed percentage of the pesticides per-acre application rate. Sometimes a deterministic spray drift model called AgDrift is used to estimate residues depositing in water at given distances from the edge of a field. Once residues are in the water, the EPA applies the model EXAMS to estimating the longevity (persistence) of residues over given periods of time (typically at application, 30, 60 and 90 days later). The EPA assumes the receiving body of water is a 6-ft deep, 2-acre pond (i.e., 3 m deep by 1 ha) of static volume (i.e., no flowing water). Furthermore, the EPA assumes volatilization is not a pathway for loss of residues from the water.

Other sources of exposure information for aquatic habitats include residue monitoring studies carried out by manufacturers or by the NAWQA Program (National Water Quality Assessment) of the U.S. Geological Survey (http://water.usgs.gov/nawqa/). However, the EPA rarely uses these data for exposure assessments because the information is not easily transferable across different cropping scenarios, landscapes, or times of applications. For example, residue data from sampling stream base flow periods would not be conservatively protective of organisms that might be exposed immediately during or after a pesticide application.

### Risk Characterization

Risk characterization can be defined as the nature and the magnitude of risk, including attendant uncertainty (NRC 1993). Risk characterization integrates species sensitivity (based on exposure-response assessment) with environmental pesticide residues (in water or on food resources). In practice, ecological risk from acute or short-term pesticide exposure is characterized as the ratio of the exposure concentration (for aquatic organisms) or dose (for terrestrial organisms) to the $LC_{50}$ or $LD_{50}$ of the most sensitive organism in the database. The ratio is termed the risk quotient (RQ). For chronic exposures over an organism's life cycle, risk is characterized as the ratio of exposure to the NOAEC (for aquatic organisms) or NOAEL (for terrestrial organisms). Uncertainty will always exist given the myriad of possible species to test, but the organisms chosen for routine testing have been studied for more than 30 years and seem to represent adequately a range of susceptibilities among fresh and saltwater invertebrates and vertebrates and among terrestrial vertebrates.

## Intersection of Risk Management and Risk Characterization

As currently practiced, the outcome of risk characterization is a simple, deterministic calculation of a number (i.e., the RQ) that represents the magnitude of difference between the exposure level and sensitivity of an organism. However, the resulting number actually means nothing in a scientific sense. Rather, its significance and acceptability must be interpreted through risk management. Thus, in addition to deciding what organisms and tests are appropriate for risk assessment, the EPA also associates levels of concern (LOC) with each RQ.

The EPA has developed LOC guidelines based on the magnitude of the acute and chronic RQ values (Table 2). The guidelines for acute exposure risk characterization are based on the classification category of the pesticide formulation product (general or restricted use) and whether the nontarget organisms are listed as endangered species. Note that endangered species are considered protected by the EPA if a larger margin of exposure (MOE; the inverse of the RQ) is achieved.

Note that the effective MOEs used for protecting nontarget organisms in the environment are lower than those used for protecting human health. For human health protection, the EPA considers effects on individuals. In contrast, from an ecological perspective, the EPA is interested in ensuring that wildlife can reproduce successfully and maintain their population in a given habitat. Thus, some loss of individuals following a severe pesticide exposure is tolerable as long as sufficient breeding individuals are unharmed.

### How the EPA Uses RQ Information

The EPA can control pesticide use in basically three ways. Registrations can be granted or suspended, tolerances (maximum residues allowed in food) can be lowered or revoked, and product labels can be made restrictive. The decisions about a number of organophosphate insecticides (OPs) made under the Food Quality Protection Act of 1996 illustrate a good example of registration and tolerance decision making. The number of OPs registered for use in fruit production has been sharply curtailed as the EPA revoked their

**Table 2. Generic risk characterization calculations and levels of concern used by the EPA for aquatic ecological risk characterization**

| Risk presumption category | Risk quotient calculation[1] | Level of concern | Effective margin of exposure |
|---|---|---|---|
| Acute high risk | $EEC/LC_{50}$ | 0.5 | 2 |
| Acute restricted use | $EEC/LC_{50}$ | 0.1 | 10 |
| Acute endangered species | $EEC/LC_{50}$ | 0.05 | 20 |
| Chronic risk | EEC/NOAEC | 1 | 1 |

[1]EEC, estimated environmental concentration; $LC_{50}$, concentration of pesticide lethal to 50% of test subjects in 96 hours; NOAEC, no observable adverse effect concentration.

tolerances owing to concerns of excessive exposure to children and nursing mothers.

If ecological risk characterization shows that pesticide residues are likely to exceed the toxicity benchmarks, the EPA will direct modifications of the product label to lower exposure. For example, to mitigate the likelihood of drifting residues from a spray application exceeding the target RQs, the EPA could impose buffer zones, or set backs from water bodies in which no spray could be applied. Often, labels will state explicitly "Do not apply directly to water, to areas where surface water is present". Other warnings state, "Do not contaminate water when disposing of equipment washwaters."

## Is the Current Ecological Risk Assessment Paradigm for Pesticides Protective Enough?

The peer-reviewed scientific literature is replete with studies of the hazards of pesticides for nontarget organisms. Whole journals such as *Environmental Toxicology and Chemistry* (published by the Society of Environmental Toxicology and Chemistry) and *Aquatic Toxicology* (published by Elsevier, Inc.) have become repositories of every imaginable pesticide hazard. Bear in mind, however, that all pesticides have associated hazards because someone or company has conducted tests at high enough doses or concentrations to show that adverse effects can occur.

Because ecological risk assessment relies on few toxicological endpoints—mortality and developmental or reproductive detriments—and few species are used (typically one or two species of saltwater and freshwater aquatic crustaceans and fish, two species of birds, and one strain of rat), the protectiveness of the current assessment paradigm has been negatively criticized and questioned. For example, has the most sensitive species actually been identified in the data gathering process? Do sublethal effects occur at residue levels that may be overlooked by just focusing on mortality or developmental or reproductive toxicity? Can ecological risk assessment be applied across bigger scales than just the farm field, and is it relevant to higher levels of organization such as populations and communities?

Each of these questions deserves a treatise of discussion in its own right. However, after more than 25 years of intensive documentation of hazards and associated exposure–response relationships in the scientific literature, the EPA's requirements for ecological fate and effects testing has done a remarkably good job of choosing the most sensitive organism upon which to base ecological risk characterization for acute and chronic toxicity. Although it is true for any one organism that sublethal effects such as enzyme inhibition, hormone titers, histopathological effects, or abnormal behavior occur at less than lethal residue levels, the concentrations associated with such effects are often significant percentages of the $LC_{50}$ or $LD_{50}$, or alternatively are still much higher than likely to occur in the environment after application consistent with label directions and good agricultural practices (Felsot 1999).

A case has been made for the inadequacy of the $LC_{50}$ in predicting population level effects (Stark and Banks 2003). Examining intrinsic rate of increase or similar parameter of population stability should be more predictive of field level effects from pesticide exposure. Although demographic studies focus on population ecology, the published experiments often test pesticide concentrations approaching the $LC_{50}$, and therefore do not reflect realistically the levels likely to be found in water. However, the EPA's use of developmental or reproductive toxicity as a hazard endpoint should increase the likelihood that any sublethal effects will not compromise population health because reproductive capacity is unlikely to be diminished when residue concentrations do not exceed the NOAEC. The value of considering both acute and chronic toxicity can be

illustrated by examining the aquatic invertebrate exposure–response parameters for spinosad, a reduced-risk insecticide certified for organic agriculture. The 48-hour acute $LC_{50}$ against *Daphnia* sp. is 14,000 ppb, but the chronic NOAEC is 0.6 ppb. Although the very low use rate of spinosad is likely to preclude contamination of water even at levels of 0.6 ppb, spinosad represents an extreme example because the mean difference between acute and chronic toxicity parameters is about 1 order of magnitude (Stark 2005).

## Glyphosate Case Study: Aquatic Hazard without Risk?

Glyphosate is generally recognized as having very low toxicity to aquatic invertebrates and vertebrates, with $LC_{50}$ values often exceeding 10,000 ppb. However, amphibians, which are not required to be studied for pesticide registration, are comparatively more susceptible to glyphosate formulations than fish and crustaceans. For example, tests of glyphosate formulated as Vision against larval amphibians yielded a comparatively sensitive $LC_{50}$ of 880 ppb (Edginton et al. 2004). Furthermore, recent research has shown that predator visual cues can hypothetically cause stress that lowers the $LC_{50}$ (Relyea 2005). Glyphosate formulated as Roundup (which contains the surfactant polyethoxylated tallowamine [POEA]) exhibited a 16-day $LC_{50}$ against wood frogs of 1,320 ppb in the absence of visual cues from a predator and 550 ppb in the presence of a predator. The wood frog was the most sensitive amphibian of six species tested.

The tests of glyphosate formulations on amphibians contrast with the conclusions based on fish and invertebrate testing reported in the EPA's Registration Eligibility Decision document (RED) for glyphosate active ingredient alone. The acute and chronic toxicity of glyphosate to an aquatic invertebrate were estimated to be >50,000 ppb. However, testing of the Roundup formulation showed that rainbow trout responded with an $LC_{50}$ of 2,300 ppb, and testing of the POEA surfactant alone gave an $LC_{50}$ of 650 ppb. Published studies have shown that the POEA surfactant in glyphosate-formulated products such as Roundup is actually the toxicant of concern for amphibians, fish, and crustaceans, rather than the glyphosate itself (Servizi et al. 1987, Howe et al. 2004, Wang et al. 2005). Nevertheless, the comparatively greater toxicity of glyphosate formulations to amphibians than fish or invertebrates seems to be the exception rather than the rule (Renner 2005).

The studies of Roundup toxicity to amphibians are a good example of hazard identification, but they are a poor indicator of risk. To determine whether risk to amphibians is likely, probable field exposure information is needed. The U.S. Geological Survey (USGS) has published monitoring data for glyphosate residues in water collected from streams in the Midwest, the region of greatest use of glyphosate owing to annual plantings of millions of acres of Roundup Ready soybean (Scribner et al. 2003). The 95th percentile of stream concentrations monitored during the time of most intense glyphosate use (i.e., postsoybean emergence) was 1.5 ppb, and the maximum found was 4.5 ppb. Integration of the maximum stream concentration with the 16-day $LC_{50}$ for the wood frog in the presence of predators yields an RQ of 0.008 (RQ = 4.5 ppb/550 ppb), well below the EPA's LOC for endangered species (Table 2).

The residues in midwestern streams likely represent runoff- and erosion-derived processes rather than direct entry because of drift. However, overspray entry would be illegal according to the Roundup product labels that state specifically, "Do not apply directly to water, to areas where surface water is present" (e.g., the Roundup Ultramax product label, EPA Registration No. 524-512). Even if Roundup should be accidentally sprayed over water, glyphosate and associated product surfactants would quickly be diluted by flowing water or quickly sorbed from the water column by sediment (Wang et al. 2005). Studies in arboreal habitats show very rapid dissipation of glyphosate itself after direct addition to ponds (Goldsborough and Beck 1989; Goldsborough and Brown 1993). Furthermore, initial concentrations in ponds directly oversprayed with Roundup (1.9 lb/acre) were less than 100 ppb. Given the low levels of glyphosate residues found (and, by implication, surfactant concentrations), the probability of glyphosate causing acute toxicity to the most sensitive frog species is very low.

A recent ecological risk assessment for over-water uses of glyphosate and various surfactants deployed a probabilistic approach wherein species sensitivity distributions were integrated over predicted and measured residue distributions (Solomon and Thompson 2003). Such probabilistic analyses produce risk characterization that takes in to account all toxicity data and a range of residue concentrations. The conclusion from this assessment was that the risk of adverse effects would be small even with the use of glyphosate and the POEA surfactant. An examination of glyphosate residues in

51 forest wetlands in conjunction with in situ bioassays by using caged amphibians seemed to validate the results of the probabilistic modeling (Thompson et al. 2004). Oversprayed wetlands contained a mean of 330 ± 110 ppb of glyphosate, but buffered habitats (30–60 m vegetated no-spray zone) averaged 30 ± 20 ppb and wetlands adjacent to sprayed zones (i.e., nonbuffered) had 180 ± 60 ppb. Although mortality of caged frogs (two species) ranged from 2 to 36%, no differences were observed among wetland classes. Thus, the authors concluded that mortality was low and uncorrelated with residue concentrations.

## Conclusions

All pesticides are hazardous in the context that at some dose or concentration adverse effects ranging from lethality to enzyme and hormone titer changes can be observed. However, knowing about a hazard does not characterize the probability of the effect occurring, nor does it help triage scarce management resources. The EPA uses ecological risk assessments to determine how older and newly registered pesticides should be managed to minimize impacts on nontarget organisms. For the most part, the EPA has selected test species that many studies have confirmed are the most sensitive with respect to acute and chronic toxicity. Even if some species are more sensitive than the ones used by the EPA for risk assessments, an examination of the actual residues occurring in the environment, rather than estimates based on modeling or simply based on laboratory studies simulating oversprays, shows that margins of exposure are sufficiently protective. Where uncertainty over likely residues and species susceptibility is high, the EPA can change label requirements to protect sensitive habitats.

## References


Duffus, J. H. 2001. Risk assessment terminology. Chemistry International 23: http://www.iupac.org/publications/ci/2001/march/risk_assessment.html#29.

Edginton, A. N., P. M. Sheridan, G. R. Stephenson, D. G. Thompson, and H. J. Boermans. 2004. Comparative effects of pH and Vision herbicide on two life stages of four anuran amphibian species. Environmental Toxicology and Chemistry 23: 815–822.

Felsot, A. S. 1999. Pesticides and salmon decline: Missing link or red herring? Agrichemical & Environmental News (May) 157: 8–11, 16 (URL: http://aenews.wsu.edu).

Fletcher, J. S., J. E. Nellessen, and T. G. Pfleeger. 1994. Literature review and evaluation of the EPA food-chain (Kenaga) nomogram, an instrument for estimating pesticide residues on plants. Environmental Toxicology and Chemistry 13: 1383–1391.

Goldsborough, L. G., and A. E. Beck. 1989. Rapid dissipation of glyphosate in small forest ponds. Archives of Environmental Contamination and Toxicology 18: 537–544.

Goldsborough, L. G., and D. J. Brown. 1993. Dissipation of glyphosate and aminomethylphosphonic acid in water and sediments of boreal forest ponds. Environmental Toxicology and Chemistry 12: 1139-1147.

Howe, C. M., M. Berrill, S., B. D. Pauli, C. C. Helbing, K. Werry, and N. Veldhoen. 2004. Toxicity of glyphosate-based pesticides to four North American Frog species. Environmental Toxicology and Chemistry 23: 1928–1938.

National Research Council (NRC). 1983. Risk Assessment in the Federal Government: Managing the Process. National Academy Press, Washington, DC.

National Research Council (NRC). 1989. Improving Risk Communication. National Academy Press, Washington, DC.

National Research Council (NRC). 1993. A paradigm for ecological risk assessment, pp. 241–356. *In* Issues in Risk Assessment. National Academy Press, Washington, DC.

National Research Council (NRC). 1994. Science and Judgment in Risk Assessment. National Academy Press, Washington, DC.

Relyea, R. A. 2005. The lethal impacts of Roundup and predatory stress on six species of North American tadpoles. Archives of Environmental Contamination and Toxicology 48: 351–357.

Renner, R. 2005. Are industry's secret "inerts" an unrecognized environmental danger? Environmental Science and Technology 39: 417A–418A.

Scribner, E. A., W. A. Battaglin, J. E. Dietze, and E. M. Thurman. 2003. Reconnaissance Data for Glyphosate, Other Selected Herbicides, their Degradation Products, and Antibiotics in 51 Streams in Nine Midwestern States, 2002. Open-File Report 03-217, U.S. Geological Survey, Lawrence, KS.

Servizi, J. A., R. W. Gordon, and D. W. Martens. 1987. Acute toxicity of Garlon 4 and Roundup herbicides to salmon, Daphnia, and trout. Bulletin of Environmental Contamination and Toxicology 39: 15–22.

Solomon, K. R., and D. G. Thompson. 2003. Ecological risk assessment for aquatic organism from over-water uses of glyphosate. Journal of Toxicology and Environmental Health B 6: 289–324.

Stark, J. D. 2005. How closely do acute lethal concentration estimates predict effects of toxicants on populations?

Integrated Environmental Assessment and Management 1: 109–113.

Stark, J. D., and J. E. Banks. 2003. Population-level effects of pesticides and other toxicants on arthropods. Annual Review of Entomology 48: 505–519.

Thompson, D. G., B. F. Wojtaszek, B. Staznik, T. Chartrand, and G. R. Stephenson. 2004. Chemical and biomonitoring to assess potential acute effects of Vision herbicide on native amphibian larvae in forest wetlands. Environmental Toxicology and Chemistry 23: 843–849.

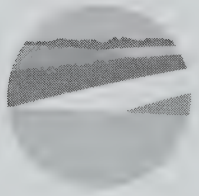
U.S. Environmental Protection Agency (EPA). 1997. Pesticide Fact Sheet: Spinosad. Office of Pesticides and Toxic Substances; Washington, DC. http://www.epa.gov/opprd001/factsheets/spinosad.pdf.

U.S. Environmental Protection Agency (EPA). 1998. Guidelines for ecological risk assessment. Federal Register 63: 26846–26924.

U.S. Environmental Protection Agency (EPA). 2004. Overview of the ecological risk assessment process in the Office of Pesticide Programs, U. S. Environmental Protection Agency. Endangered and threatened species effects determinations. Office of Prevention, Pesticides and Toxic Substances, Washington, D.C. URL: http://www.epa.gov/oppfead1/endanger/consultation/ecorisk-overview.pdf.

U.S. Environmental Protection Agency (EPA). 2005. OPPTS Test Guidelines Series 850, Ecological Effects (page last updated 2/18/05): http://www.epa.gov/opptsfrs/OPPTS_Harmonized/850_Ecological_Effects_Test_Guidelines/Drafts/.

Wang, N., J. M. Besser, D. R. Buckler, J. L. Honegger, C. G. Ingersoll, B. T. Johnson, M. L. Kurtzweil, J. MacGregor, and M. J. McKee. 2005. Influence of sediment on the fate and toxicity of a polyethoxylated tallowamine surfactant system (MON 0818) in aquatic microcosms. Chemosphere 59: 545–551.



# Pesticides and Aquatic Communities: How Unintentional Exposures Impact Nontarget Organisms

Rick Relyea

Pesticides can offer tremendous benefits in controlling undesirable pests, and a great deal of research has been devoted to understanding how to design chemicals to kill unwanted target organisms. At the same time, we also are concerned with the effects that these chemicals might have on nontarget organisms, including humans. Because there are thousands of chemicals, the traditional testing of pesticides has been standardized to focus on a few species of animals under highly controlled laboratory conditions. The general objective of this endeavor has been to determine the lowest concentration of pesticide that causes no harmful effect on the test animal. This is a very efficient approach to testing a large number of chemicals and has produced an extensive database of expected pesticide toxicity values for a few species that are thought to be representative of their groups (e.g., mammals, birds, and fish). Although this approach is highly logical, it relies on a number of implicit assumptions that currently are being tested in aquatic ecosystems.

First, we assume that toxicity estimates derived under laboratory conditions can be extrapolated to nature. A number of recent experiments have examined how including components of the natural world (e.g., UV radiation, temperature variation, pH variation, and predatory stress) impacts standard toxicity tests. These studies have found that natural stressors can have major effects on the lethality of pesticides, in some cases making them nearly 50 times more lethal than was previously known (Lohner and Fisher 1990; Zaga et al. 1998; Boone and Bridges 1999; Taylor et al. 1999; Boone and Semlitsch 2001; Relyea and Mills 2001; Relyea 2003, 2004a; Relyea et al. 2005b). Thus, toxic effects observed in laboratory experiments could drastically underestimate the toxicity under natural conditions.

Our second assumption is that pesticides have a single specifically designed mode of action (e.g., nerve agents). Despite their intended design, pesticides can have a wide range of effects not only on survival but also on the behavior, growth, and development of nontarget organisms, suggesting multiple modes of action for pesticides (Little 1990, Relyea and Mills 2001, Relyea 2004b). Moreover, we assume that pesticides follow a "dose-response" curve, such that high doses have harmful effects on organisms, whereas low doses have no effects. This traditional perspective is now being challenged by research demonstrating that some pesticides can have very different modes of action at low doses compare with high doses (e.g., endocrine disrupters; Hayes et al. 2002). Therefore, we need to better understand all of the possible modes of pesticide action (including sublethal doses) to assess pesticide risk.

The third assumption is that single-species toxicity tests can be used to predict the effects of pesticides in ecological communities. Because most animals in nature live within complex food webs in which species interact with one another, there is a wide range of potential direct and indirect effects of pesticides that can have both positive and negative effects on nontarget organisms. Importantly, these effects can cascade through a food web and have unforeseen impacts on different trophic levels (Mills and Semlitsch 2004, Relyea 2005a, Relyea et al. 2005). Hence, to understand the complete impact of pesticides in nature, we need to investigate organisms that are embedded within a community of other organisms.

When we consider these assumptions in light of recent research, it becomes clear that pesticide effects can be dramatically different than one would predict from traditional laboratory experiments. Although much of the research has been conducted in aquatic ecosystems, there is no inherent reason to consider that the phenomena being discovered are restricted to these systems.

## References


Boone, M. D., and R. D. Semlitsch. 2001. Interactions of an insecticide with larval density and predation in experimental amphibian communities. Conservation Biology 15: 228–238.

Boone, M. D., and C. M. Bridges. 1999. The effect of temperature on the potency of carbaryl for survival of tadpoles of the green frog (*Rana clamitans*). Environmental Toxicology and Chemistry 18: 1482–1484.

Hayes, T. B., A. Collins, M. Lee, M. Mendoza, N. Noriega, A. A. Stuart, and A. Vonk. 2002. Hermaphroditic, demasculinized frogs after exposure to the herbicide atrazine at low ecologically relevant doses. Proceedings of the National Academy of Sciences USA 99: 5476–5480.

Little, E. E. 1990. Behavioral toxicology: stimulating challenges for a growing discipline. Environmental Toxicology and Chemistry 9: 1–2.

Lohner T. W., and S. W. Fisher. 1990. Effects of pH and temperature on the acute toxicity and uptake of carbaryl in the midge, *Chironomus riparius*. Aquatic Toxicology 16: 335–354.

Mills, N. E., and R. D. Semlitsch. 2004. Competition and predation mediate the indirect effects of an insecticide on southern leopard frogs. Ecological Applications 14: 1041–1054.

Relyea, R. A. 2003. Predator cues and pesticides: a double dose of danger for amphibians. Ecological Applications 13: 1515–1521.

Relyea, R. A. 2004a. Synergistic impacts of malathion and predatory stress on six species of North American tadpoles. Environmental Toxicology and Chemistry 23: 1080–1084.

Relyea, R. A. 2004b. The growth and survival of five amphibian species exposed to combinations of pesticides. Environmental Toxicology and Chemistry 23: 1737–1742.

Relyea, R. A. 2005a. The impact of insecticides and herbicides on the biodiversity and productivity of aquatic communities. Ecological Applications 15: 618–627.

Relyea, R. A. 2005b. The lethal impacts of Roundup and predatory stress on six species of North American tadpoles. Archives of Environmental Contamination and Toxicology 48: 351–357.

Relyea, R. A., and N. Mills. 2001. Predator-induced stress makes the pesticide carbaryl more deadly to grey treefrog tadpoles (*Hyla versicolor*). Proceedings of the National Academy of Sciences USA 98: 2491–2496.

Relyea, R. A., N. M. Schoeppner, and J. T. Hoverman. 2005. Pesticides and amphibians: The importance of community context. Ecological Applications 15: 1125–1134.

Taylor, S. K., E. S. Williams, and K. W. Mills. 1999. Effects of malathion on disease susceptibility in Woodhouse's toads. Journal of Wildlife Disease 35: 536–541.

Zaga, A., E. E. Little, C. F. Rabeni, and M. R. Ellersieck. 1998. Photoenhanced toxicity of a carbamate insecticide to early life stage anuran amphibians. Environmental Toxicology and Chemistry 17: 2543–2553.

# Killing Pests or Managing Risk? IPM As a Strategy for Sustaining Pesticide Technology as a Viable Tool

Allan S. Felsot

When the initial throng of baby boomers became teens during the 1950s, a new music embodied by the pelvic thrusts of Elvis was a sore in the eyes of their parents. But it passed into the mainstream as the music and hair of the Beatles for the next wave of boomers created for the next sets of parents another round of indigestion. And that queasy feeling passed into the mainstream, displaced by the headache of heavy metal and punk and so on through rap. Looking back, I am amused by how the new and the different passes into our everyday lexicon and commercial acceptance so easily as if we went to sleep and woke up to it as expectantly as a greeting from the early morning sun. And as I come with trepidation to the precipice of fulfilling the challenge of telling you why the reports of the death of integrated pest management (IPM) are premature, I'm struck by the feeling that I don't even need to define the abbreviation because it is now not only part of our mainstream but also has evolved into a political slogan for any and all agendas.

Maybe some in the crop production community feel that IPM has passed its utility. I can see why they might feel that way because our chemists just keep inventing wonderful new elixirs that seem to work even better than last year's stuff but at lower rates and with less hazards to the applicator. I think, however, that this viewpoint is naïve and suggests a dose of "déjà vu all over again." After all that we've been through over the past 50 years, with the constant pummeling of modern agricultural techniques by countless environmental advocacy groups, and with the barrage of scientific articles declaring a pesticide hazard around every corner, how can anyone think the "war" is won?

I offer several hypotheses to explain the troubling perspective that somehow crop protection practices don't need IPM any more. First, so many groups with varied agendas have bastardized the definition of IPM that we forgot that it is a dynamic ecologically based risk management system rather than a panoply of off-the-shelf products (Zalom 2001). Second, the ingenuity of chemistry has lulled us into complacency about the costs of the technology and the problems of sustaining new products. Third, the amazing effectiveness of pesticides in concert with the greater dependence on international markets and standards has displaced the focus from making an annual profit to "counting dead pest bodies."

## Will the Real IPM Please Stand Up?

I'm sure my faculty colleagues have become aware, perhaps painfully, of the tendency of policy makers and administrators to focus increasingly on outcomes (while still focusing on how many publications and grants are produced each year). How many people did you reach, affect, or change. Or how much money will this save for us or them, and so on. As scientists trained in experimentation and hopefully still exercising the practice of science, we're interested (hopefully) in understanding how and why the world works as it does. So in our reductionist tendencies to understand life's great mysteries, we are reduced to fitting our academic interests into a preconceived notion of what the outcome should be. Applying this concept to IPM funding, I've noted a comparatively new partnership between the Environmental Protection Agency (EPA) and the American Farmland Trust (AFT) to fund IPM programs that are outcome based ("FQPA/Strategic

Agricultural Initiative Program Grants" at http://www.aftresearch.org/grant/grant_info.php). The program has adopted the Rensselaerville Institute outcome funding framework to force longtime practitioners of IPM research and educators into concocting estimates of outcomes such as how many growers will be changed; the reduction in use of EPA-targeted pesticides (a euphemistic phrase for OP insecticides); and progress toward implementation of ecologically based pest management or biointensive IPM. To quote from a recent request for applications in EPA Region 10 of the United States (which includes the Pacific Northwest), "Proposals are ranked on potential for success and potential to achieve the two desired outcomes of reducing pesticide use and/or risk and increasing the adoption of biointensive IPM."

Such outcomes may be the epitome of the problem regarding the incessant discussions of the future of IPM. First, it essentially gives weight to the myth that IPM's objective is to reduce pesticide use. The stated outcome goal presumes the existence of a technology called biointensive IPM as an off-the-shelf remedy rather than a virtual reality concept made up to recreate the definition of IPM for sale to a new batch of legislators and their staff who are assigned to read the plethora of reports about how bad (or good) things are.

If policy makers are really interested in fundamental change among growers, they better first agree on what IPM is really about. Without a coherent, logical, and reality-based definition, how is progress toward implementing rational pest management programs to be measured (Kogan 1998)? A compendium of IPM definitions that covers the years 1959–1999 (http://www.ippc.orst.edu/IPMdefinitions/) suggests two basic types of definition are circulating. One perspective is IPM as an integration of many tools for controlling pests, and an avoidance of pesticides, to be used only as a last resort. Such a definition is definitively outcome based—you can measure the reduction in pesticide use, for example, and it fits well with the EPA/AFT granting program. The other perspective is strategy focused—how do you know what to do and when to do it, or do you need to do anything? The specific tools used once a decision is made necessarily can affect successful implementation of your whole strategy, but the use or nonuse of any one tool is not the measurement point for success.

So what is IPM? The definition you gravitate to will depend on your agenda. After reviewing tens of definitions, Kogan (1998) described IPM as "a decision support system for the selection and use of pest control tactics, singly or harmoniously coordinated into a management strategy, based on cost/benefit analyses that take into account the interests of and impacts on producers, society, and the environment." This definition suggests the ecological and economic concepts that gird IPM as well as include some perspective that risk assessment and management are integrated. Everyone should be happy with his definition because it includes all stakeholders. Surely diehard pesticide users still relying on the old saw of prophylactic treatments can certainly support the concept of "decision support system." After all, if not for the fundamental knowledge of an agroecosystem as dependent on the functional mechanics of ecological relationships, i.e., the foundation of IPM, how would you know what week to start spraying?

As further explication of the role of IPM in correctly applying control tactics, especially pesticides, let's presume that an ancient method putatively capable of controlling moth larvae has been resurrected. According to Pliny the Elder (23-79 AD), "Apples were said to be preserved from the attack of caterpillars as well as from rot by touching the top of the tree with the gall of a green lizard" (Shepherd 1939)." Use of IPM as a decision support system would ask certain questions and guide appropriate use of this "reduced risk" biointensive technology. For example, we need to know how long the lizard gall works. We need to answer whether its application should be timed as close as possible to when the earliest instars are about to hatch. After all, it is a reasonably well-known principle from insect toxicology that the earlier instars are more susceptible on a biomass basis than the later instars. Someone has to scout for the eggs so the gall is used correctly. Otherwise to use it at the wrong time risks an ineffective waste of time as well as money that went into capturing the lizards. Wouldn't it be just as egregious if we sprayed a pesticide when there was no pest problem or at the wrong time in a pest's life cycle? Perhaps you might call the practice an application of unmitigated gall.

## Aren't Chemicals Grand ... and Ephemeral?

If all a grower cares about are outcomes in one season, then there is no reason to sit through another lecture about IPM, because there is a pesticide out there for everyone. And those tools work damn well. However, pesticides in use today provide a false sense of security because they are so much better (i.e., more selective, more toxicologically benign, less disruptive to nontarget organisms and communities) than yesterday's

pesticides. Thus, they may have lulled us into thinking that the process of IPM is passé.

Perhaps a trip down memory lane is in order to lull us from our stupor. Pesticides have been a technological option for millennia, but pesticides that work well were inventions of the mid-twentieth century. DDT was the silver bullet that saved millions of lives as louse borne epidemic typhus was on the verge of taking off in Europe in the 1940s. Malaria was the scourge of tropical climates everywhere, as our soldiers in the Pacific learned during the war. Again, DDT was the simple, magical elixir to defeat the nonhuman foe. But those fantasy pictures of the neatly coiffed housewife in dress and high heels blissfully pumping sprays of DDT around her kitchen to control flies turned dark as the silver bullet was transferred to the agricultural sector.

Not too long after DDT jumped from public health savior to the over used method of controlling all types of agricultural pests, problems began to multiply (Stern et al. 1959). Entomologists quickly observed insects of non-economic importance cross the threshold from secondary pests to primary pests. Resurgence of pest populations despite DDT application signaled something was going awry. The need for increasing DDT application rates to achieve acceptable control after just a few years of use came so swiftly as to make creationists begin to believe in the process of evolution. One by one, insect species succumbed to resistance development as if they had read Darwin's *Origin of Species*.

Lest my friends in the weed control world think they are not victims of lack of implementation of fundamental principles of IPM, let them count the number of weed species that developed resistance to new herbicides like imidazolinones and sulfonylureas as rapidly as wildfire could scorch rangelands infected with cheatgrass. Is glyphosate next, or just a low-level infection because its specific monogenic mode of biochemical action has become applicable over huge acreages of weeds that never before could experience its wrath in the midst of growing crops. How certain are we that in the absence of an ecological perspective on population dynamics and economic injury levels the new biotechnology-derived host plant resistance engineered with single or even stacked genes will stave the evolutionary imperative of differential reproduction?

Some may profess that IPM has nothing to do with pesticide resistance management strategies, but in short, they couldn't be more wrong. Monitoring populations whether for density or for resistant alleles is most definitively part and parcel of IPM. Whereas chemical class rotation (and transgenic crop-free refuges) have been touted as slowing or even reversing resistance development, adhering to use of a pesticide when only necessary is still the best way to relieve resistance pressure. The idea is to have available pesticides (and resistant crop varieties) that work in an outbreak, when they are really needed.

Agricultural chemical manufacturers are dwindling in numbers, having consolidated so rapidly as to create proverbial soup lines of agricultural scientists looking for gainful employment. New instrumentation to automate the organic synthesis laboratory with combinatorial chemistry has made it even harder for chemists to stay off the streets. The result has been good for the proverbial bottom line, but the grower is not on that line. Stockholders come before growers. It is up to the agricultural community to sustain its technological tools. And the only way to do that is to understand that they are best used in response to decision making that is informed by knowledge of functional principles of applied ecology and statistically based population measurement systems and economics. To apply pesticides without the adequate use of decision systems is to not act in one's self interest but to give up to manufacturers who focus on the quarter, not the decade. Should we abandon IPM now, the current tools used as a result of crop protection decisions will be just as ephemeral as the utility of the great miracle insecticide DDT in previous generations.

I have three caveats about being enamored with the newly registered reduced risk pesticides and any thought they might save us in the absence of an IPM program. First, many problems still exist without solutions amenable to chemical technology. For example, plant viruses and some other insect-transmitted disease microorganisms have no chemical solution. Exotic species are found often in today's highly mobile world, and new pest problems arise continuously. Thus, the trend in pesticides for more selectivity and safety will not solve new problems until we understand population ecology.

My second caution about the new pesticides is that their cost of development and registration is becoming so high and the return on investment so laggardly relative to the length of patent protection, that minor crops supportive of the farm economies outside of the Corn Belt do not have the products they need, especially when exotic pests become established. Third, the so called reduced risk pesticides are not just about being less hazardous to humans and terrestrial and aquatic

wildlife. Successful crop protection with the new pesticides must rely on their potential for conservation of natural enemies and beneficial arthropods such as bees. The neonicotinoid insecticide imidacloprid is an example of a compound with a nearly innocuous toxicological profile that has come under suspicion because of evidence of effects on increasing fecundity of phytophagous mites (James and Price 2002), high toxicity to some coccinellid (ladybird beetle) predators (James 2003), and potential cause of bee toxicity when used as a seed treatment in sunflower production (Suchail 2001, Decourtye 2004). To sum up, there is no free lunch.

## Are International Markets Pushing Us Away from Profitability?

Let me share my perspective a Corn Belt boy who went west to the great Pacific Northwest, land of salmon worship and Microsoft. In Washington state, a source of pride is our number one position in pome fruit production. But viable growers know that our exports keep the industry alive because the domestic market is too small. Adding insult to injury is the displacement of U.S. apple culls to the juice processors because China has about six times more apple acreage than in the whole of the U.S. and they know where to send its fruit. The U.S. consumers' attitude about blemishes is the least of worries now. Rather, our international markets have become our customers, and we bow to their wishes. And what do they demand? Like victims of multiple personality, they simultaneously demand for all practical purposes zero pesticide residues (even though their domestic farmers use them as liberally as any in the west) and zero evidence of pesticide damage! The paradox came home to roost over the past 2 years with warnings from our Taiwan trading partners that they will not tolerate seeing any more codling moths in fruit shipments. They were worried essentially about two previous detections. That's not two whole shipments contaminated, but two apples. Fittingly, all farmers, whether described as conventional or certified organic, use pesticides, just different kinds. But the pesticides themselves are not sufficient to control every last codling moth, they will never be, and we never expected them to be. In keeping international markets open, growers must realize that they have little control over rational standards of pest control, so the focus must be on profitability, not dead insect bodies. Thus, if pesticides are not the prefect solution to the paradoxical Asian demands for fruit perfection and no pesticide residues, then growers must rely on a decision support system that reduces technological inputs as much as possible. My view is that pesticides will be here to stay, but less will be used as we realize that overkill does not prevent irrational market forces from robbing us of potential profit.

## Conclusions

Pesticide technology is far safer than ever before. It is toxicologically more innocuous. The efficacious per acre application rates are much lower than even two decades ago because of toxicokinetic and toxicodynamic selectivity combined with a comparatively higher potency against pests than against nontarget natural enemies. But we shouldn't be lulled that these advances have come independently of the widespread implementation of the principles of IPM. To the contrary, chemicals only seem the main solution because IPM has engendered a perspective of successful crop protection that fortunately has changed manufacturers' response in the choice of products developed. By adhering to the correct functional definition of IPM as a decision support system, or perhaps even more descriptively as applied population and systems ecology in concert with risk management, we will sustain the newer safer and more selective pesticides as a very useful technology far better than our predecessors of the last century. To turn our back on the foundational principles of IPM is to cut off our nose to spite our face.

## References


Decourtye, A., J. Devillers, S. Cluzeau, M. Charreton, and M.-H. Pham-Delegue. 2004. Effects of imidacloprid and deltamethrin on associative learning in honeybees under semi-field and laboratory conditions. Ecotoxicology and Environmental Safety 57: 410–419.

James, D. G. 2003. Pesticide susceptibility of two coccinellids (*Stethorus punctum picipes* and *Harmonia axyridis*) important in biological control of mites and aphids in Washington hops. Biocontrol Science and Technology 13: 253

James, D. G. 2003. Pesticide susceptibility of two coccinellids (*Stethorus punctum picipes* and *Harmonia axyridis*) important in biological control of mites and aphids in Washington hops. Biocontrol science and technology **13**: 253-259.259.

James, D. G., and T. S. Price. 2002. Fecundity in twospotted spider mite (Acari: Tetranychidae) is increased by direct and systemic exposure to imidacloprid. Journal of Economic Entomology 95: 729–732.

Kogan, M. 1998. Integrated pest management: historical perspectives and contemporary developments. Annual Review of Entomology 43: 243–270.

Shepard, H. H. 1939. The chemistry and toxicology of insecticides. Burgess Publishing Company, Minneapolis, MN.

Stern, V. M., R. F. Smith, R. van den Bosch, and K. S. Hagen. 1959. The integrated control concept. Hilgardia 29: 81–101.

Suchail, S., D. Guez, and L. P. Belzunces. 2001. Discrepancy between acute and chronic toxicity induced by imidacloprid and its metabolites in *Apis mellifera*. Environmental Toxicology and Chemistry 20: 2482–2486.

Zalom, F. G. 2001. Pesticide use practices in integrated pest management, pp. 275–283. *In* R. I. Krieger [ed.], Handbook of pesticide toxicology, vol. 1. Principles. Academic, New York.

# The Devil and Leon Higley: An IPM Story

Leon G. Higley

This essay comes in advance of a debate/point-counterpoint discussion on the relevancy and usefulness of integrated pest management (IPM). The impetus for this discussion is the current planting of transgenic crops with resistance genes for pests that often may not reach damaging numbers. But the same discussion could be motivated by dozens of other observations: the unnecessary use of seed treatments or soil insecticides, the unnecessary use of insecticides or fungicides, the continuing failure to block the introduction of new pests such as soybean aphid, the failure to use more crop rotation, the explosion in pest resistance to management tactics, and on and on.

I have many problems in entering a debate about IPM. First, I detest the confrontational, black or white, yes or no format of debate. Second, as my friend Mike Gray put it, I'm "an IPM guy", which is true given that I did my graduate work under Larry Pedigo, an international leader in IPM who made seminal contributions to the field. Also, I've written lots of articles and books on IPM, developed IPM programs, trained IPM students, taught IPM courses—the whole smash. And third, there is the danger that if you work as the devil's advocate, you might start thinking things like "Well Ol'Scratch may have a bad rep, horns, and stink of brimstone, but some of his ideas sound pretty good." This last point should worry me most, because I so consistently miss deadlines, I already consider myself foreman of Hell's road crew (you know ... "The road to Hell is paved with good intentions"). Nevertheless, I agreed to enter into this IPM–non-IPM debate, even at risk of my soul.

What is IPM? Despite more than 50 years of discussion, you cannot get agreement on this simple point even among professionals. More disturbing, many who claim to know, don't. A little history will illustrate this last point and much more about IPM.

Undoubtedly, the ideas underlying IPM (e.g., not every potential pest becomes a real pest, the importance of most pests depends on their numbers) are of great antiquity. You have only to look at the Bible, Sumerian texts, or other ancient writings to recognize that discussions of locust plagues and other pests date from our earliest written records. The invention of agriculture itself necessarily involved coping with pests. Moreover, just as the invention of mathematics was a consequence of agriculture (to keep track of amounts of grain and their value), so were other advances such as architecture and pottery at least partially a consequence of needing to secure harvested grain against pests.

For millennia, the techniques to cope with pests were so few and so limited there was no need to look beyond the question of "What can we do?" However, in the mid-1800s the application of science to agriculture and technological advances started changing the rules of the game. By the 1930s with the rise of synthetic pesticides, farsighted individuals began asking different questions. Rather than "What can we do?," they asked "How should we act against pests?" and, more radically, "Do we even need to act against all pests?" About the same time, certain scientists, mostly entomologists I'm proud to say, started looking at which factors in nature cause animal populations to grow and crash.

These various issues meshed in the mid to late 1950s leading to what would ultimately be called IPM. In 1959, four entomologists (Stern, van den Bosch, Smith, and Hagen) from the University of California published a paper offering their thoughts on how to combine the use of insecticides with biological control. They

called their ideas the "Integrated Control Concept," and they argued for the use of multiple tactics against pests, defined the general equilibrium position of a pest population, and developed the concepts of pest status, economic damage, economic injury levels (EILs), and economic thresholds (ETs). You can tell how important they thought their ideas were, because they submitted what I think is the single most important paper ever written in applied entomology to *Hilgardia*, a local California journal, where it was published. As important as their paper was (even if the authors didn't recognize its significance), it had some significant omissions and one unproven assumption. First, definitions of many key concepts were missing or incomplete, and it wasn't until 1972 that Larry Pedigo and a graduate student, Jay Stone, developed the mathematical definitions of economic damage, economic injury levels, and economic thresholds. Until Pedigo and Stone developed these formulae and associated procedures for their use, it was impossible to actually implement the ideas first proposed in 1959. Second, the proposition that control methods must be integrated was untested and has remained mostly untested since. In fact, some people (like me) think that the need for "integration of control" isn't true, at least not as a general principle.

Often this is the end of the IPM history lesson, but the true story is much more international. A group of Australian entomologists/ecologists (Geier, Clark, Hughes, and Morris) looked at many of the same questions about pests and proposed a less detailed but equally radical departure from convention. They argued that trying to "control" pests with tactics such as insecticides was little more than trying to "bulldoze nature." Instead, they said that pests must be "managed," with an explicit goal of damping peaks of large pest populations but never trying to reduce populations to the limits of available technology. Moreover, they pointed out that in failing to embrace management, all tactics used against pests were ultimately doomed to failure because pest populations would adapt to the tactic.

Unfortunately, the lasting impact of these insights mostly was for "integrated control" to become "integrated pest management." Only the IPM guys and gals who looked at pest management as a issue of applied ecology fully embraced the ideas of the Australians. Eventually, sampling plans and some economic thresholds started appearing, but mostly IPM was a word to use on grant proposals or to put on extension circulars. Pathologists and weed scientists never fully embraced the underlying concepts of IPM, and, in fairness, many concepts had limited applicability to pests other than insects. But even in entomology, biological control workers (I'm tempted to call them zealots, but I wouldn't want this to sound too opinionated) argued that IPM was just "insecticide management." The real action was in developing new ways to kill pests: with new introductions of insect parasitoids or disease, with new antibiotic plant varieties, with sterilization of insects, with pheromones, with new kinds of insecticides, and, most recently, with biotechnology.

What evidence do I have for this jaundiced view? The best historical review of applied entomology in the mid 20th century is a book by Perkins called *Insects, Experts, and the Insecticide Crisis*. In that volume, Perkins argues the core issue was a debate between proponents of pest eradication and biological control—IPM doesn't even make it to the conference table. As another example, soybean has the most highly developed pest management programs of any crop, including more sampling programs and economic injury levels and thresholds. In 1994, Peterson reviewed pest management decision tools (EILs and ETs) and noted that of the 39 insect pests that can occur on soybean, only 10 had calculated EILs. So, in the crop with the most advanced IPM programs, only about 25% of the pests even had the basic tools for IPM. Some might argue that IPM is more than thresholds and EILs, which is true, but without thresholds you can't answer the most basic question: do we need to take action against a given pest population.

So what is IPM? I think it is the application of ecological principles to reduce the impact of pest species, while sustaining profitability, environmental quality, and longevity of management tactics. It isn't "insecticide management," it doesn't (necessarily) have anything to do with insecticide reduction, and it isn't just rational use of control procedures. At the core, it must include ecology coupled with economics to provide the most rational approaches for dealing with pests. Most of the formal part of IPM (sampling and decision making) has focused on whether to take action against a pest. Unfortunately, too little formal thought has been given to choice of tactic or longevity of tactic. For example, lots of people are now interested in "resistance management," a subject that in its very name ironically suggests that IPM failures (the development of resistance) are inevitable.

The limitations of IPM are not related to any flaw in its principles, difficulties in developing programs, or, even (as guys like me like to complain) lack of funding. IPM is limited for three reasons. First, it is not a technology

for solving pest problems, it is a set of procedures for using technology. Second, the goals of IPM are often, maybe usually, different from the goals of producers. And third, rather than solving producer problems, IPM procedures can exacerbate problems.

Perhaps it is in human nature to want simple, complete solutions. I'd pay plenty for the "get-rid-of-fat-and-live-forever" pill, but I don't seem to be willing or able to achieve the same goal through diet and exercise. New technologies are exciting. Ways to use a technology, and, worse, limitations to the use of a technology, are not exciting. IPM is about how to use technologies against pests, it is not about new methods for killing bugs. Clearly, what we want is the silver bullet: a technology that will make our pest problems go away. For a time we had one, DDT, but when DDT lost its luster with the discover of its deleterious nontarget effects, not only were we without a silver bullet but also all our bullets, all insecticides, were to be abhorred.

I've long thought it strange that we invest our technologies with virtues and flaws, when it is our use of those technologies that matter (a very IPM perspective). For some reason, I wrote a small verse on this very issue 30 years ago in college, so here's my chance to be a published poet (and yes, I was reading too much Alexander Pope before I wrote this).

**Fear Not the Hammer**

Fear not the hammer,
Fear the hand.
Tools are not evil,
'Tis the mind of man.

Fear not the sword,
Fear its bearer.
Weapons are lifeless,
Man the terror.

What does *Fear Not the Hammer* have to do with IPM and insecticides? If we didn't associate our pest control techniques with virtues or villainies, we might be able to look more dispassionately at their use. Instead, insecticides are evil, biological control is pure and harmless, plant resistance is natural, and biotechnology is an unholy desecration of nature. None of these perspectives are true, and yet even our governmental regulations reflect many of these attitudes. If our tools for dealing with pests hadn't been so limited for millennia, perhaps we would regard how we use our pest control technologies as being as important as the technologies themselves. Instead, IPM seems like a nagging parent to a teenager. "Billy, did you sample that alfalfa? Don't you go using that sprayer unless you did all your sampling and calculating. Billy! Are you listening to me?"

What about the goals of IPM? Well, if entomologists don't agree on a definition for IPM, is it any surprise that they don't agree on the goals? Often mentioned are issues such as increasing sustainability, tolerating pests at some levels, conserving resources (including natural enemies and management tactics), reducing or eliminating pesticide use (I don't agree with this one), and improving profitability. These mostly sound like good goals, but how do they mesh with producer goals? Certainly our ideal image of a farmer is someone bound to the land, a steward, who reaps nature's bounty while preserving the source of this largesse. Most farmers I've known **are** stewards of their land who want to preserve farming and their way of life. But their overriding goal, the one concept that occupies their thought more than any other is much more basic. Survival, economic survival.

If your core goal is economic survival, obviously your abilities to experiment and accept risks are limited. Additionally, economic realities have forced American farmers to expand their acreage to achieve economies of scale, which expands their work load, which limits the time they have for pest management. And there is the psychological burden of routinely living on the edge. Now what does IPM ask of farmers? First, scout your thousand acres of corn before you take any action. Second, accept some risk, because our predictions about pests, even the very best predictions, might be off one time in twenty. And third, don't always use the same familiar, inexpensive, management practice because pests might become resistant.

Almost all writers on IPM acknowledge that IPM practices are only part of the entire crop production system. But what we usually fail to acknowledge is that the entire crop production system may work against IPM. When a company claims "season-long" control of some pest, the promise of an insecticide spray or a new genetic trait that eliminates the potential problem and offers peace of mind is very alluring. IPM asks more of producers in an era where they have less—less time, less money, and less tolerance for risk. Even if IPM is the only rational approach to achieving our goals in coping with pests, and I think it is, short of regulation or other mandatory requirements what practical hope does it have?

When listening to discussions about gene deployment strategies or putting *Bacillus thuringiensis* (*Bt*) genes for

beetles or caterpillars in all kinds of crops, I occasionally hear discussions about EPA regulations or about technical barriers. But I rarely hear discussions about the wisdom of this approach. It is difficult for me to see many differences between covering the planet with DDT and covering the planet with *Bt* transgenic crops. Of course, this is an exaggeration, but the observation that too little attention is given to avoiding the failures of the past is not.

The failure to learn or accept certain kinds of scientific evidence is not unique to IPM; maybe it's just another feature of human nature. I find myself in a society where a significant portion of the population is debating the merit of scientific principles established more than a century ago. In my opinion, like too many religious debates in history, the science versus creationism issue in the United States has much more to do with the political influence of certain religious viewpoints than it has to do with sincere questions of faith versus reason. Ironically, immediate evidence of evolution is readily available through such trivial observations as the rapid evolution of pathogens and insects. Where you stand on evolution doesn't matter much to a new drug-resistant malaria *Plasmodium* or a mutated bird virus that crosses over into human lungs. IPM is caught in this absurd battle over evolution, because evolution, especially the power of natural selection, is the single most important argument for IPM. You can't wantonly use a tactic to kill pests, without selecting for those pests that aren't killed by the tactic—evolution in action.

Earlier I said debating about IPM is like fighting the devil for my soul, but this was the wrong religious analogy. Many of us can see that new technologies are being used with the same lack of wisdom as were old technologies, sowing the seeds of their future failure. Until we find a way to make *how* we use technology as important as *having* a technology to use, IPM will be marginalized. Thus, I increasingly fear that those of us arguing for IPM and the need to make it work are like the Trojan seer Cassandra, able to see the future but unable to make anyone believe.

# Crop Protection Technology Conference

## Proceedings

UNIVERSITY OF ILLINOIS EXTENSION

2007

# Crop Protection Technology Conference

Farming Agriculture and the Environment

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# Illinois Crop Protection Technology Conference Program

## Wednesday Morning, January 3

**Opening Session** • Illini Rooms A, B, and C • *Todd Gleason, Moderator*

(1.5 CCA credits in Integrated Pest Management and 1.0 CCA credit in Crop Management)

| | |
|---|---|
| 9:00 AM | Welcome and Opening Remarks • *Mike Gray and Kevin Steffey* |
| 9:15 AM | Lessons from a "Quiet" 2006 Season—What Lies Ahead? |
| | Introduction • *Todd Gleason* |
| 9:20 AM | Climate Patterns: Past, Present, and Future • *James Angel* |
| 9:35 AM | Crop Production • *Emerson Nafziger* |
| 9:50 AM | Weed Management • *Aaron Hager* |
| 10:05 AM | Questions and Answers |
| 10:25–10:40 AM | Break • South Lounge |
| 10:40 AM | Rust Is Here, Now What? • *Suzanne Bissonnette* |
| 10:55 AM | Nematode Management • *Terry Niblack* |
| 11:10 AM | Insect Management • *Kevin Steffey* |
| 11:25 AM | Questions and Answers |

Although the 2006 growing season was relatively "quiet" and crop prospects were excellent, a review of prevailing conditions and pest issues always presents opportunities for learning. Problems with crop development and pests developed, despite the general goodness of the season, and agricultural issues changed or evolved, presenting the possibility for improvements. Panel members will interact to address field crop issues in 2006—What happened? How can we learn from our experiences in 2006? Could a good crop year have been better? A look back to look ahead.

11:45 AM–1:00 PM Lunch, on your own

## Wednesday Afternoon, January 3

*Symposia A, B, and C run concurrently from 1:00–2:45 PM*

**Symposium A • Healthy Plants: Is Your Disease Threshold Damaged?** • Illini Rooms A and B • *Suzanne Bissonnette and Bruce Paulsrud, Moderators*

(1.5 CCA credits in Integrated Pest Management)

The symposium will address current issues regarding disease management of field crops. Disease thresholds have been successful management techniques. What are the thresholds for important field crop diseases? What does independent science tell us regarding the thresholds and prediction models for these diseases?

| | |
|---|---|
| 1:00 PM | Identification and Management of Soybean Diseases • *Glen Hartman* |
| 1:25 PM | Integration—The Key to Managing Fusarium Head Blight (Scab) in Wheat • *Paula McMullen* |
| 1:50 PM | Fungicides on Hybrid Corn: Yield Impact of Foliar Disease Control • *Gary Munkvold* |
| 2:15 PM | Application Strategies to Improve Crop Health • *Robert E. Wolf* |
| 2:40 PM | Questions and Answers |

**Symposium B • Seed and Soil: Some Basics of Crop Agronomics** • Ballroom • *Mike Hellmer, Moderator*

(0.5 CCA credit in Soil and Water Management, 0.5 CCA credit in Nutrient Management, and 0.5 CCA credit in Crop Management)

Even though 2006 was a relatively "quiet" year in terms of problems in crop growth and management, there is always more to learn with regard to "managing the manageable" in order to keep yields moving up. This symposium will include a review of recent research on the related issues of corn roots, tillage, and crop nutrition, and will conclude with a presentation on the ever-critical issue of establishing the best possible stand.

| | |
|---|---|
| 1:00 PM | Tillage System Effects on Root Growth and Fertilizer Placement Considerations • *Richard Cruse* |
| 1:35 PM | Why is My Field Showing Potassium Deficiency? • *Fabián Fernández* |
| 2:10 PM | The Ideal Corn Stand • *Emerson Nafziger* |

**Symposium C • Wheat Management in Illinois** • Rooms 314A and B • *Fred Kolb, Moderator*

(1.0 CCA credit in Integrated Pest Management and 0.5 CCA credit in Crop Management)

Winter wheat acreage in Illinois has fallen by some two-thirds over the past three decades, due to yield and price instability and

to high yields of corn and soybean, with which wheat competes. Good yields in recent years and more favorable prices in 2006 have more people thinking about wheat. This symposium will provide information on recent developments in wheat breeding and management, including management of important pests.

| | |
|---|---|
| 1:00 PM | Fitting Wheat into Illinois Cropping Systems • *Emerson Nafziger* |
| 1:25 PM | Wheat Disease Management • *Gregory Shaner* |
| 1:50 PM | Development of Fusarium Head Blight Resistant Wheat Varieties • *Fred Kolb* |
| 2:15 PM | Managing Insects in Wheat: An Overview • *Doug Johnson* |
| 2:45–3:15 PM | Break, South Lounge |

*Symposia A, B, and C repeated concurrently from 3:15–5:00 PM*

**Symposium A (repeated) • Healthy Plants: Is Your Disease Threshold Damaged?** • Illini Rooms A and B

**Symposium B (repeated) • Seed and Soil: Some Basics of Crop Agronomics** • Ballroom

**Symposium C (repeated) • Wheat Management in Illinois** • Rooms 314A and B

| | |
|---|---|
| 5:00–6:30 PM | IFCA-Sponsored Mixer<br>Illini Union South Lounge |

This mixer is sponsored by the Illinois Fertilizer and Chemical Association. It is intended for everyone to meet with speakers, sponsors, and committee members in an informal atmosphere.

## Thursday Morning, January 4

*Symposia D, E, and F run concurrently from 8:00–9:45 AM*

**Symposium D • Glyphosate Resistance: It's Not Just Limited to Crops Anymore** • Illini Rooms A and B • *Aaron Hager, Moderator*

(1.5 CCA credits in Integrated Pest Management)

Glyphosate-resistant weed biotypes have become significant challenges for weed management practitioners across many areas of the United States. At least two species of *Amaranthus* have been confirmed resistant to glyphosate. Horseweed, lambsquarters, and giant ragweed are other annual weed species in which glyphosate-resistant populations have been selected or are suspected. This symposium will focus on the occurrence of glyphosate resistance in Palmer amaranth and waterhemp and how glyphosate resistance may be spread across populations.

| | |
|---|---|
| 8:00 AM | Impact of Glyphosate-resistant Palmer Amaranth on Southeastern Agriculture • *Stanley Culpepper* |
| 8:20 AM | Glyphosate-resistant Waterhemp: Our Experiences in Missouri • *Kevin Bradley* |
| 8:40 AM | Predicting the Evolution and Spread of Glyphosate-resistant Waterhemp • *Patrick Tranel* |
| 9:00 AM | Preparing for the Inevitable—A Prescription for Resistance • *Dawn Nordby* |
| 9:20 AM | Questions and Answers |

**Symposium E • Insect Management Issues: Did Events in 2006 Set Us Up for 2007?** • Ballroom • *David Feltes, Moderator*

(1.5 CCA credits in Integrated Pest Management)

This session will provide management information for two old insect foes (European corn borers and western corn rootworms) and two newer invasive insect pests (soybean aphids and western bean cutworms). Aphids presented fewer challenges to Illinois producers in 2006; however, 2007 may be another story. Updates on the latest research efforts at Iowa State University and the University of Illinois will be provided for this key insect pest. Western bean cutworms continued to expand their range eastward during 2006. How significant is the economic threat posed by this new invader? What are the best management approaches? These questions and others will be answered. Bt and non-Bt tactics can be used for western corn rootworms, western bean cutworms, and European corn borers. Management considerations for economic insect control include: selecting the most appropriate transgenic hybrid (single-, double-, or triple-stacked), or not selecting a Bt hybrid; use of a seed treatment in a refuge; application of conventional insecticides (granular vs. liquid); and implementing the most appropriate refuge strategy (if Bt is used) for a given operation. More choices were available for insect control in 2006, with potentially more options available in 2007. Come prepared to challenge these speakers with your insect management questions.

| | |
|---|---|
| 8:00 AM | Soybean Aphid Management: What Works and What Doesn't? • *Matthew O'Neal* |
| 8:25 AM | Western Bean Cutworm and the Invasion of Illinois Corn: It's Like Déjà vu All Over Again • *Marlin Rice* |
| 8:50 AM | Transgenic Corn Rootworm Hybrids: Assessing Performance in a Variant Western Corn Rootworm Arena • *Mike Gray* |
| 9:15 AM | Seed-applied Insecticides, Soil Insecticides, and Bt Corn: Their Roles in Corn Production • *Kevin Steffey* |
| 9:30 AM | Questions and Answers |

**Symposium F ✦ The Influence of Organic Markets and Urban Perspectives on Agrichemical Applications** ✦ Rooms 314A and B ✦ *Russel Higgins and Elizabeth Wahle, Moderators*

(1.0 CCA Credit in Professional Development and 0.5 CCA credit in Integrated Pest Management)

Wal-Mart is selling more and more organic produce and grocery items. Celebrities and famous athletes repeatedly tout the "purity" and "enhanced" quality of organic foods. Regardless of your personal feelings about organic foods, this segment is growing rapidly and will influence the traditional commercial agrichemical industry even in a large grain state like Illinois. Organic crops and the increasing demographic of rural citizens who are generations removed from the farm are changing how custom applicators operate in many parts of rural Illinois. Learn what organic certification means and what it takes to maintain harmony with organic producers and non-farm landowners.

| | |
|---|---|
| 8:00 AM | Who's Your Neighbor? ✦ *Jack Erisman* |
| 8:20 AM | Managing the Risks of Custom Application: An Industry Perspective ✦ *Jean Payne* |
| 8:35 AM | Surviving on the Fence Between Emerald City and Oz ✦ *Donald Meyer* |
| 8:55 AM | Illinois Department of Agriculture Perspective ✦ *Gerald Kirbach* |
| 9:15 AM | Identifying and Protecting Organic Farms from Contamination with Prohibited Substances ✦ *Cissy Bowman* |
| 9:35 AM | Questions and Answers |
| 9:45–10:15 AM | Break, South Lounge |

***Symposia D, E, and F repeated concurrently from 10:15–12:00 NOON***

**Symposium D (repeated) ✦ Glyphosate Resistance: It's Not Just Limited to Crops Anymore** ✦ Illini Rooms A and B

**Symposium E (repeated) ✦ Insect Management Issues: Did Events in 2006 Set Us Up for 2007?** ✦ Ballroom

**Symposium F (repeated) ✦ The Influence of Organic Markets and Urban Perspectives on Agrichemical Applications** ✦ Rooms 314A and B

## Thursday Afternoon, January 4

| | |
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| 12:00 NOON–12:15 PM | A light lunch will be provided to people who attend the closing session. Lunches will be available in the South Lounge. |

**Closing Session** ✦ Illini Rooms A, B, and C ✦ *Mike Gray, Moderator*

(0.5 CCA credit in Integrated Pest Management and 0.5 CCA credit in Professional Development)

**Strengthening the Partnership with the Illinois' Agribusiness Community**

The longevity of this conference through almost six decades is a testament to the enduring partnership that exists among the University of Illinois, University of Illinois Extension, and the agribusiness sector. The organizers of this conference value this relationship and hope to synergize this partnership by exploring new collaborative opportunities in this quickly evolving crop protection arena. Dr. Wendy Wintersteen, Dean of the College of Agriculture, Iowa State University, will describe an innovative approach in Iowa (Corn and Soybean Initiative) that is designed to revitalize the important linkage between our land grant system and the agribusiness retail sector. Ultimately, this program aims to improve the implementation of relevant and research-based crop protection information to producers. Following Dr. Wintersteen's presentation, Dr. Robert Hoeft, Head of the Department of Crop Sciences, and Jean Payne, President of the Illinois Fertilizer and Chemical Association, will offer their reactions and comments regarding this Iowa State University partnership with Iowa retailers. Is this or a similar approach needed in Illinois? Please come ready to interact with these speakers and offer your insights.

| | |
|---|---|
| 12:15 PM | Overview ✦ *Mike Gray* |
| 12:20 PM | Is Extension Delivering Relevant and Effective Integrated Pest Management Corn and Soybean Programs? ✦ *Wendy Wintersteen* |
| 12:50 PM | Reaction and Proposal—College of ACES, UIUC; Illinois Fertilizer and Chemical Association |
| | *Robert Hoeft, Head, Department of Crop Sciences, University of Illinois at Urbana-Champaign* |
| | *Jean Payne, President, Illinois Fertilizer and Chemical Association* |
| 1:15 PM | Adjourn |

# Program Participants

**Angel, James** • Illinois State Climatologist, Illinois State Water Survey, Champaign, IL

**Ayers, Steve** • Extension Unit Educator, Champaign Extension Unit, University of Illinois Extension, Champaign, IL

**Bissonnette, Suzanne** • Extension Educator, Integrated Pest Management, Champaign Extension Center, University of Illinois Extension, Champaign, IL

**Black, Kevin** • Insecticide and Fungicide Manager, Growmark, Inc., Bloomington, IL

**Bowman, Cissy** • CEO, Indiana Certified Organic, Clayton, IN

**Bradley, Kevin** • Assistant Professor, Division of Plant Sciences, University of Missouri, Columbia, MO

**Bretthauer, Scott** • Extension Specialist, Pesticide Safety Education, Department of Agricultural and Biological Engineering, University of Illinois, Urbana-Champaign, IL

**Cruse, Richard** • Professor, Department of Agronomy, Iowa State University, Ames, IA

**Culpepper, Stanley** • Assistant Professor and Extension Agronomist, Rural Development Center, University of Georgia, Tifton, GA

**Erisman, Jack** • Producer, Pana, IL

**Fernández, Fabián** • Assistant Professor, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL

**Feltes, David** • Extension Educator, Integrated Pest Management, Quad Cities Extension Center, University of Illinois Extension, East Moline, IL

**Gleason, Todd** • Media Communications Specialist, Information Technology and Communication Services, University of Illinois, Urbana-Champaign, IL

**Gray, Mike** • Professor, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL

**Hager, Aaron** • Assistant Professor, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL

**Hartman, Glen** • USDA-ARS, Associate Professor, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL

**Hellmer, Mike** • Agronomy Information Manager, Pioneer Hi-Bred International, Inc., Mahomet, IL

**Higgins, Russel** • Extension Educator, Integrated Pest Management, Matteson Extension Center, University of Illinois Extension, Matteson, IL

**Hoeft, Robert** • Head, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL

**Johnson, Douglas** • Professor, Department of Entomology, University of Kentucky, Princeton, KY

**Kirbach, Gerald** • Manager, Permits and Downstate Field Operations, Bureau of Environmental Programs, Illinois Department of Agriculture, Springfield, IL

**Kolb, Fred** • Professor, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL

**McMullen, Marcia** • Professor, Department of Plant Pathology, North Dakota State University, Fargo, ND

**Meyer, Donald** • Unit Leader, McLean Extension Unit, University of Illinois Extension, Bloomington, IL

**Munkvold, Gary** • Associate Professor, Department of Plant Pathology, Iowa State University, Ames, IA

**Nafziger, Emerson** • Professor, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL

**Niblack, Terry** • Professor, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL

**Norby, Dawn** • Extension Specialist, Weed Science IPM, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL

**O'Neal, Matthew** • Assistant Professor, Department of Entomology, Iowa State University, Ames, IA

**Paulsrud, Bruce** • Extension Specialist, Pesticide Applicator Training and Plant Pathology, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL

**Payne, Jean** • President, Illinois Fertilizer & Chemical Association, Bloomington, IL

**Reed, Rick** • Member, Illinois Agricultural Aviation Association, Mattoon, IL

**Rice, Marlin** • Professor and Extension Specialist, Department of Entomology, Iowa State University, Ames, IA

**Reifsteck, John** • Producer, Champaign, IL

**Runkle, Kevin** • Regulatory Affairs Manager, Illinois Fertilizer & Chemical Association, Bloomington, IL

**Shaner, Gregory** • Professor, Department of Botany and Plant Pathology, Purdue University, West Lafayette, IN

**Steffey, Kevin** • Professor, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL

**Tranel, Patrick** • Associate Professor, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL

**Wintersteen, Wendy** • Dean and Director, College of Agriculture, Iowa State University, Ames, IA

**Wahle, Elizabeth** • Extension Educator, Horticulture, Edwardsville Extension Center, University of Illinois Extension, Edwardsville, IL

**Wolf, Robert E.** • Extension Specialist, Application Technology, Kansas State University, Manhattan, KS

# Lessons from a "Quiet" 2006 Season—What Lies Ahead?

## Climate Patterns: Past, Present, and Future

*Jim Angel*

Over the years, there has been increasing concern about climate change, especially as the result of human activities such as introducing more greenhouse gases and aerosols into the atmosphere and changing the land surface. An examination of global mean temperatures shows an increase over time that may be attributed to these activities. What about Illinois? Have we seen significant changes in the climate of Illinois? Long-term temperature, precipitation, drought, and snowfall records will be presented. In addition, this paper will focus briefly on the three most recent growing seasons. The outlook for the coming growing season will be discussed during the presentation, but will not be discussed here for reasons provided elsewhere in this paper. I use the term "normal" to refer to an average for the period 1971–2000. This is standard practice for describing the modern-day climate of a site or region. The traditional seasons discussed in this paper are winter (December–February), spring (March–May), summer (June–August), and fall (September–November).

## Past Climate Patterns

### *Annual Patterns*

Figure 1 is the time series of average annual precipitation in Illinois expressed as a percentage of normal. The first 20 years of the record from 1840 to 1860 are represented by only one to four stations. More stations were added each year so that by the 1880s, the number of stations ranged from 20 to 30, depending on the year. The 20th century records were represented by 50 to 60 high-quality, long-term records. As a result, the precipitation record from 1840 to 1860 may be viewed as less certain, whereas the precipitation record from the 1880s to the present is viewed as more certain.

The precipitation pattern in Illinois can be described in three periods. The first period is from the 1840s to 1900s and is distinguished by increasingly drier conditions. In fact, 1901 is the driest year in the historical record, with only 26.32 inches of rain, 64% of normal. The second period is from the 1900s to the 1960s, when precipitation overall remained drier than the modern day. The third period is from the 1960s to the present, when conditions rapidly became wetter. Most of this increase in precipitation during the third period occurred in spring, summer, and fall but not winter. Other studies have indicated that the number of heavier rainfall events during the 20th century has increased in conjunction with the increase in precipitation in Illinois (e.g., Karl and Knight 1998).

The shift from drier conditions in the early portion of the 20th century to the wetter conditions since the 1960s is reflected in the drought record for Illinois, as well. An examination of the statewide Palmer Drought Severity

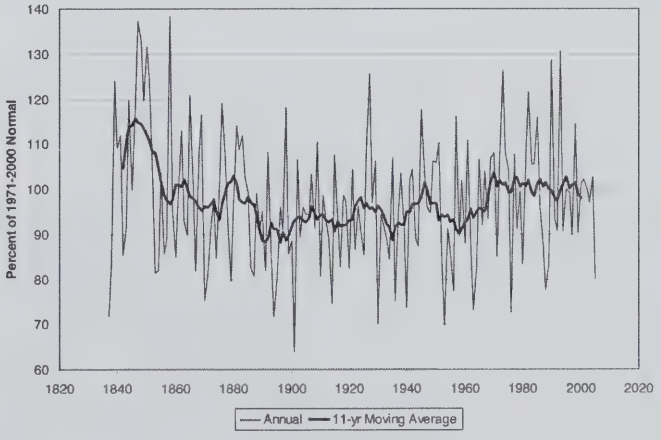


**FIGURE 1 • Average annual precipitation in Illinois, as expressed as a percentage of normal.**

Index (PDSI), a measure of monthly drought conditions based on both temperature and precipitation and available only since 1895, indicates that eight "extreme" droughts (indicated by a PDSI value of 4 or less) occurred in the record from 1895 to 1965. The lowest PDSI on record was −6.9 in July 1934. Since 1965, only the drought of 1988 qualified as a statewide extreme drought. The drought of 2005 did not qualify because it was confined primarily to northern and western Illinois, whereas southern Illinois enjoyed near-normal precipitation. Even so, the core drought area attained PDSI values of 4 or less, achieving extreme drought status.

Figure 2 is the time series of average annual temperatures in Illinois. As with precipitation data, average annual temperatures in the early years are reconstructed from only a handful of stations. However, by the 1870s, the number of stations increased, along with the confidence in the series. Overall, the temperatures in the 1800s were cooler than they are today. From the 1890s to the 1930s, the statewide temperature warmed by about 2.5°F. From 1930 to 1980, the temperatures cooled by about 2°F. Since 1980, the temperature has warmed by about 1°F. The net result is that Illinois temperatures warmed by approximately 1°F over the historical record from 1840 to 2005. The temperature changes discussed here are in general terms to illustrate the major patterns—the exact years and magnitudes of change vary slightly depending on the analysis used. From Figure 2, the most significant warming to take place in Illinois was in the late 1800s and early 1900s and occurred before greenhouse gases were believed to have any impact on the climate. The modest warming of the past two decades reverses the cooling trend that apparently ended around 1980.

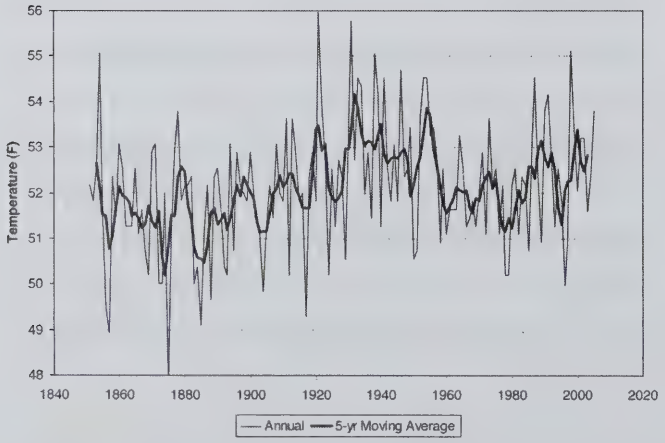


**FIGURE 2 • Average annual temperature in Illinois.**

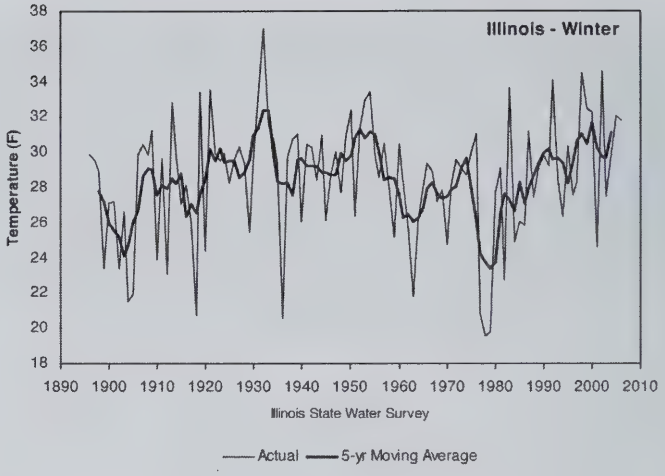


**FIGURE 3 • Average winter (December–February) temperature in Illinois.**

However, temperatures during the decades in the 1930s and 1950s are still considered warmer than those of the most recent decade.

### *Seasonal Patterns*

Most of the change in annual temperatures over time occurred during the winter months (Figure 3). The sequence of warming, cooling, and then warming identified in the annual temperatures is clearly seen here. Furthermore, the magnitudes of change are considerably larger. For example, the range of winter temperatures in the historical record is about 17°F, compared to only 8°F in the annual temperatures. Even so, the overall increase in winter temperatures over time is only about 1°F in

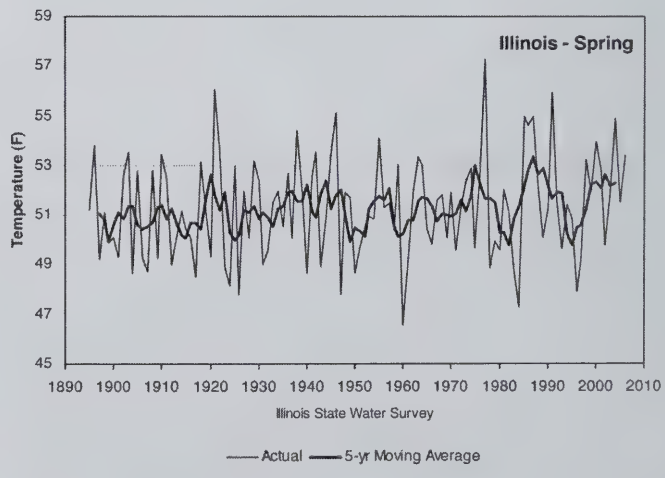


**FIGURE 4 • Average spring (March–May) temperature in Illinois.**

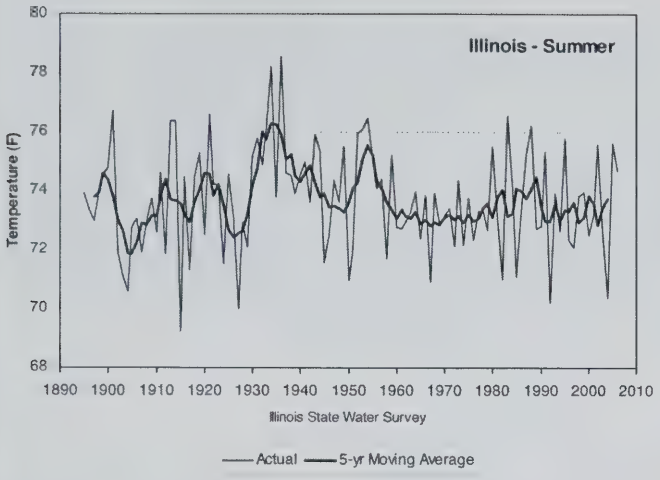


**FIGURE 5 • Average summer (June–August) temperature in Illinois.**

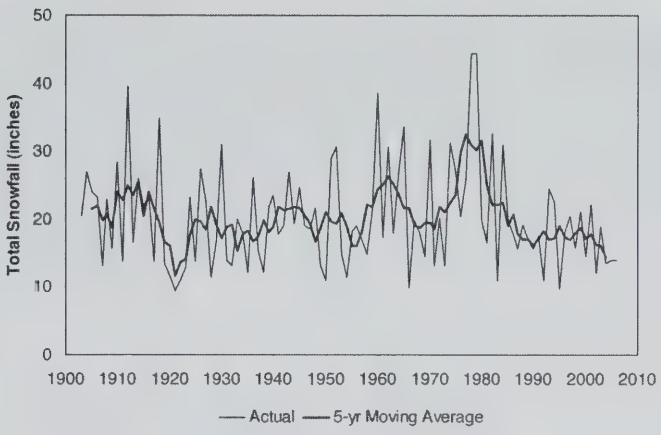


**FIGURE 7 • Average snowfall-season (September–May) snowfall in Illinois.**

Figure 3. Since 1895, the coldest winter occurred in 1978 (19.6°F); the warmest winter was in 1932 (37.0°F).

The sequence of warming, cooling, and then warming in the annual and winter temperature records is absent in spring records (Figure 4). However, temperatures have increased by approximately 1°F since 1895. The coolest spring on record was in 1960 (46.6°F); the warmest spring was in 1977 (57.3°F).

For summer (Figure 5), the most unusual feature is the sudden warming that occurred in the decades from the 1920s to the 1930s. It is probably no surprise that the summers of the 1930s during the so-called Dust Bowl were the warmest on record. A secondary peak occurred in the mid 1950s. This period from the 1930s to the 1950s was about 2°F warmer than pre-1930. The period after the 1950s was cooler, as well, but not as cool as the pre-1930 period. Another interesting feature of summer records is the low year-to-year variation in temperature during the decades of the 1960s and 1970s. The period since 1980 has seen a return to higher year-to-year variation. Since 1895, the two warmest summers on record have been in 1936 (78.6°F) and 1934 (78.2°F). The coolest summer on record was in 1915 (69.2°F), although it should be noted that 2004 was the fourth coolest summer, at 70.4°F.

For fall (Figure 6), the temperatures exhibit no long-term trend. In recent years, the period from 1998 to present has been a little warmer than the period from 1980 to 1997. Since 1895, the warmest fall was in 1931 (60.3°F); the coldest fall was in 1976 (48.6°F).

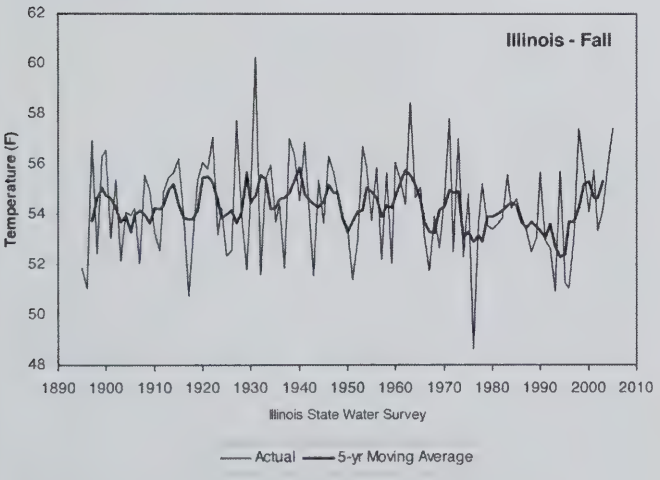


**FIGURE 6 • Average fall (September–November) temperature in Illinois.**

Another feature of the winter climate of Illinois is snowfall. A reconstruction of the average snowfall in Illinois is shown in Figure 7. There are no long-term trends in snowfall. However, the snowy winters of the late 1970s and early 1980s are outstanding in the record. That period coincided with the trend toward colder winters (Figure 3). Snowfalls since the early 1980s have been noticeably less. Considering that the period-of-record average snowfall is 20.1 inches, 15 of the last 20 snow seasons have been below average. Snowfall ranged from 9.4 inches in 1920–1921 to 44.5 inches in 1978–1979.

From an agricultural point of view, the trend toward more precipitation and fewer droughts in the past 30 to 40 years is probably the most favorable development. However, the flip side is that the increased precipitation includes increases in heavy rainfall events, resulting in more flooding and more soil erosion. During the last

century, most of the large temperature changes have occurred in winter. Temperatures during spring, summer, and fall show no significant warming. Despite the negative impacts of some recent years, such as the drought of 2005, conditions during the growing season in the later portion of the historical record have been much better than the series of hot, dry summers in the 1930s.

## Current Climate Patterns

### *The 2004 Growing Season*

Favorable weather during the 2004 growing season helped produce record yields in corn, soybean, sorghum, and alfalfa. Obtaining record yields in four main crops in Illinois in a single year has never happened before and reflects the remarkably favorable growing conditions of that year. Spring conditions in 2004 could be described as warm (3°F above normal) with a dry April (1.87 inches) between a wet March (4.27 inches) and May (6.88 inches)—ideal for field work in April. Summer temperatures were 3°F below normal with near-normal rainfall (12.11 inches, 0.55 inch above normal). Research conducted at the Illinois State Water Survey (Changnon and Changnon 2005) documented an unusually high number of clear days that summer. More clear days combined with cooler temperatures and ample soil moisture meant that plants were near their maximum productivity, with minimum stress, all summer. The end of the growing season was capped by a September that was both warm (1.7°F above normal) and dry (2.48 inches below normal), which aided in the rapid maturing and dry down of the crops.

### *The 2005 Growing Season*

The 2005 growing season was preceded by the sixth wettest January on record, with 5.39 inches of precipitation. This resulted in widespread flooding of streams and rivers, as well as a considerable amount of water standing in field. This proved to be important in the forthcoming drought because the key components of the hydrological system (soil moisture, lakes, streams, and groundwater) were fully recharged. The flooding was followed by the second driest spring statewide since 1895. Concerns about drought began to emerge in late May and June, as soil moisture was being depleted faster than normal. By summer, a significant drought had developed in northern and western Illinois, as rainfall deficits for 2005 had reached 8 to 12 inches below normal in those areas. Meanwhile, southern and parts of central Illinois had received some relief from the unprecedented passage of four tropical storms. Unlike the drought in 1988, which spanned the Midwest, the drought in 2005 was largely confined to Illinois. As a result, the impact on commodity prices was minimal. Despite unfavorable growing conditions in areas of Illinois, yields of corn and soybean were better than expected. Factors contributing to this occurrence included better plant genetics; the lack of extremely hot weather in July and August; timely rains, especially from the four tropical storms that moved up from the Gulf of Mexico; and starting the growing season with excellent soil moisture (Kunkel et al. 2006).

### *The 2006 Growing Season*

The weather for the 2006 growing season was generally favorable for Illinois, except for areas around Quincy and to the east of St. Louis. Those two areas experienced persistently dry conditions throughout the growing season, although not as severe as occurred in 2005. Otherwise, Illinois experienced near-normal temperatures and rainfall in the spring and summer. Spring temperatures were only 1.6°F above normal, with rainfall of 12.24 inches (0.97 inch above normal). Summer temperatures were 0.8°F above normal with rainfall of 11.10 inches (0.45 inch below normal).

## Outlook for the 2007 Growing Season

The National Weather Service's Climate Prediction Center (http://www.cpc.noaa.gov) produces the official forecast or outlook for the next month and for 3-month periods for the next 13 months. Because these are updated twice a month for the 1-month forecast and once a month for the 3-month periods, the outlooks will not be discussed in this paper. At the time of writing (October 2006), a moderate El Niño event had developed in the Pacific Ocean basin. The strength and impacts of this event will be discussed during the presentation.

## References


Changnon, S.A., and D. Changnon, 2005. *Unique 2004 Growing Season Weather Conditions Resulting in Record High Crop Yields in Illinois and the Midwest.* ISWS DCS 2005-01, Illinois State Water Survey, Champaign, IL, 19 pp.

Karl T.R., and R.W. Knight, 1998: Secular trends of precipitation amount, frequency, and intensity in the USA. *Bulletin of the American Meteorological Society,* 79:231–241.

Kunkel, K.E. (ed), J.R. Angel, S.A. Changnon, R. Claybrooke, S.D. Hilberg, H.V. Knapp, R.S. Larson, M. Palecki, R.W. Scott, and D. Winstanley, 2006. *The 2005 Illinois Drought.* ISWS IEM 2006-03, Illinois State Water Survey, Champaign, IL, 80 pp.

# Lessons from a "Quiet" 2006 Season—What Lies Ahead?

## Crop Production

*Emerson D. Nafziger*

After the "trying" year of 2005 in some parts of Illinois, there was real relief when the weather in 2006 was favorable for timely planting of corn. Planting took place at a rapid pace, with corn planting in Illinois 73% complete by the end of April and 95% complete by May 14. Then the weather turned damp and cool, causing delays in soybean planting and some serious stand challenges in both corn and soybeans. This was followed by temperatures in the 90s for about a week at the end of May, which caused a growth spurt in crops that were emerged, brought wheat maturity on rapidly, and allowed a fast finish to planting. Emergence was very good in most fields.

Summer weather had its normal ups and downs in Illinois, but most areas got enough rainfall to keep crops growing fairly well. There was enough dry weather in June, and a lack of excessive rainfall, such that root development was good as roots grew deeper into soil moisture. Dry weather was also good for wheat, which was harvested early, with the highest statewide yield (67 bushels per acre) ever in Illinois. Rainfall patterns were mixed, though, with parts of western Illinois receiving less rainfall in June and July than in 2005, while other areas had above-normal rainfall in July. Growing degree day accumulations were close to normal, so with the early planting, corn pollination started a little early. Pollination was successful in most fields but was followed by high temperatures in the last half of July into early August. This caused some kernel abortion, and "tip-back," or unfilled kernels at the outer end of the cob, was common.

August weather was very good in most areas, with adequate rainfall and moderate temperatures. Concerns about high temperature and drought stress lessened as both corn and soybean "redeveloped" green leaf area in late August, and fill conditions in early September were very good, with yield prospects improving as maturity was delayed. Corn harvest started more or less on time, but soybean harvest was delayed.

Predicted yields of corn and soybeans in Illinois in 2006 are second among Illinois yields, trailing only 2004, with corn currently estimated at 169 and soybean at 50 bushels per acre (NASS, November Crop Report). Corn yields by crop reporting district show more than normal consistency from north to south, with the exception of the Southwest Crop Report District, which experienced some very dry weather (Table 1). Some of our early data show some greater than average yield loss when corn follows corn in the drier areas of western Illinois, which, along with dry weather in spots, may have contributed to lower overall yields in some areas.

What "troubles in paradise" did we see in Illinois in the mostly good year 2006?

- There was a rash of reports of unusual plant symptoms in corn in late June, especially from areas in western Illinois, including some fields where it was dry and some where moisture was adequate. Plants showed unusual bends in stems, with some stem pith discoloration in streaks. No definitive cause was found for this problem. Stinkbug was invoked as one possibility, but the distribution of the problem suggests that this was not the primary cause. Most affected fields seem to have yielded well, indicating that symptoms seen before pollination did not carry through to yield loss.

**TABLE 1 • Corn yield projections by Illinois Crop Reporting District. Projections released in early November lowered corn and soybean yields slightly, to 169 and 50, respectively (source: NASS).**

| | Corn | | Soybean | |
|---|---|---|---|---|
| District | 2005 | 2006 | 2005 | 2006 |
| | *bu per acre* | | | |
| Northwest | 140 | 185 | 48 | 57 |
| Northeast | 129 | 178 | 43 | 52 |
| West | 141 | 166 | 46 | 49 |
| Central | 146 | 185 | 51 | 57 |
| East | 158 | 179 | 51 | 55 |
| West Southwest | 151 | 165 | 46 | 48 |
| East Southeast | 139 | 160 | 45 | 50 |
| Southwest | 133 | 127 | 41 | 42 |
| Southeast | 130 | 147 | 43 | 45 |
| **IL** | **143** | **171** | **46.5** | **51** |

- Despite generally good corn stands, cutworms reduced stands and yields in some fields. Some seedling anthracnose was also noted. Seed-treatment insecticides and Bt traits seem to have a positive influence on corn stands. Seed-treatment insecticides are also helping soybean stands.
- Dry weather effects in some areas reminded us that corn and soybeans are not in fact "drought proof," despite improvements in vigor, roots (probably), and canopy health that have helped keep plants growing when it's dry. Still, there were some reports of much lower yields in some corn-following-corn fields in some areas, and it is clear that increasing acreage of continuous corn will present ongoing challenges.
- One of the most unusual and vexing problems in 2006 was the scattered incidence of "short ear syndrome," aka "beer-can ears." After seeing this problem on and off for more than 10 years, we still do not have a full picture of cause and effect with this disorder. In 2006, it showed up very unexpectedly in some high-yield-potential fields in northern Illinois, including some that were irrigated. We have variously invoked the possibility of herbicide effects, foliar fungicides, low temperatures, genetics, and just about everything else. To date, no clear picture has emerged. We do know that this disorder cost up to 100-bushel yield losses in some fields, and it's clearly a problem that needs some attention.

# Lessons from a "Quiet" 2006 Season—What Lies Ahead?

## Weed Management

*Aaron G. Hager*

It seems likely that some weed control practitioners would agree that describing the 2006 season as "quiet" is appropriate, whereas others perhaps would argue "raucous" might better capture the sentiments of the season. Regardless of whether you consider weed management in 2006 as quiet, raucous, or something else completely, several occurrences and observations from the 2006 season warrant discussion in this "season recap" and perhaps deserve heightened attention now, at the outset of 2007.

### Crop Injury from Herbicide Carryover

The 2006 weed management season began where it left off in 2005, on a dry note. Soil moisture levels were depleted in several areas of Illinois in 2005, including hard-hit areas north of Bloomington. We had revisited the topic of herbicide carryover toward the end of 2005 and speculated that rotational crop injury might occur from reduced dissipation of herbicide residues. Our speculation was confirmed when instances of crop injury caused by herbicide carryover began to occur.

Although the reports of rotational crop injury spanned several herbicide active ingredients and products applied during 2005, soybean injury caused by carryover of mesotrione-containing products was frequently reported. In contrast to the often-observed pattern of crop injury (i.e., injury generally confined to overlaps, field "hot spots," etc.) caused by herbicide carryover, many instances of mesotrione carryover encompassed large areas of soybean fields (sometimes entire fields). Discoloration or yellowing of soybean leaves was quite evident but often subsided following a precipitation event. Effects (if any) on soybean seed yield are, at this time of writing, largely unknown.

### Increased Frequency of Biennial Weed Species

Anecdotal observations suggest that Illinois farmers are encountering more challenges from biennial weed species. Weed species that complete their life cycle over a 2-year period may find a home in agronomic production systems in which tillage is reduced or eliminated.

A contemporary example of a such a biennial weed species is poison hemlock (*Conium maculatum*). Poison hemlock is commonly found in pastures and along railroad rights-of-way, roadsides, and other nondisturbed areas but is becoming increasingly common in reduced- and no-till corn and soybean fields. Farmers and other weed control practitioners who have experienced difficulty controlling poison hemlock in the spring prior to crop planting may want to consider investigating fall application as a possible way to improve overall success. A fall application would be better suited for targeting rosette-stage plants, and higher herbicide rates may provide better control with fewer planting restrictions, compared with lower application rates in the spring.

### A New Weed Control Paradigm for Corn

Widespread adoption of glyphosate-resistant soybean varieties, with a concomitant use of glyphosate for weed control, has become the norm for Illinois soybean farmers. Heretofore limited adoption of glyphosate-resistant corn hybrids provided a disruption of the "glyphosate-only cycle" across many Illinois acres, but that began to change in 2006. Estimates of the percentage of acres planted with glyphosate-resistant corn hybrids varied during 2006 but generally were above 30%.

One may speculate whether the adoption of glyphosate-resistant corn hybrids will "transform" corn weed control programs into something resembling contemporary soybean weed control programs. In other words, will total postemergence weed control programs in corn become as common as they are in soybeans today? Without much doubt, there were some who attempted to manage weeds in glyphosate-resistant corn in a manner similar to the way they manage weeds in soybeans (i.e., by using a single postemergence application of glyphosate). Under the "right" conditions, it is altogether likely that excellent weed control and corn yields can be achieved with this type of program. But this type of program also carries the greatest risk for significant yield loss if weeds are allowed to compete too long or if significant weed populations emerge after the initial glyphosate application and are left uncontrolled.

Thus, total postemergence weed control programs can be viable options, but close and careful attention must be given to the timing of the initial application as well as to accurately assessing the need for subsequent applications. Illinois farmers are poised to plant a significantly higher percentage of their corn acres in 2007 with glyphosate-resistant corn hybrids compared with previous years. Although this technology offers some enticing advantages, it is unlikely to solve all perceptible weed management problems. Keep in mind that although this technology represents a new *tool* for weed control, the *principles* of weed control in glyphosate-resistant corn hybrids are the same as they are in conventional corn hybrids.

## Volunteer Corn in Soybeans

Many cornfields across the state "greened up" following the 2005 harvest, not because of weed growth but because of the "second" corn crop of the season (i.e., volunteer corn). Although some of the corn seed was lost because some seed germinated in the fall and some seed died during the winter months, volunteer corn was a common weed problem in Illinois soybean fields during 2006. Glyphosate is very effective for control of volunteer corn in soybeans; however, many weed control practitioners reported that glyphosate provided poor control of volunteer corn in 2006. Several of these instances occurred in fields where glyphosate-resistant corn had *not* been planted in 2005, causing some to ponder whether the volunteer corn was resistant to glyphosate, and, if so, how this trait came to occur in a field where no glyphosate-resistant corn previously had been planted. Tankmixing an ACCase-inhibiting herbicide with glyphosate often improved control of volunteer corn compared with glyphosate alone, but it seemed that all not ACCase-inhibiting herbicides performed with equivalent efficacy.

## Horseweed or Marestail?

The academic debate over the "correct" name of the species took a backseat to the very real problem of poor marestail control with glyphosate, undoubtedly attributed (in many instances) to glyphosate-resistant populations. Because glyphosate use is pervasive both prior to planting (i.e., burndown) and following crop emergence (i.e., postemergence in glyphosate-resistant varieties/hybrids), identification of horseweed populations from Illinois that are not adequately controlled by glyphosate necessitates that farmers consider alternative options to control these populations. Chemical options may not always provide an adequate level of control, but preplant tillage (when feasible) can greatly reduce marestail populations that are present prior to planting.

## Inconsistent Weed Control with Glyphosate

Similar to past seasons, several weed species seemed to challenge the "one product for all needs" reputation of glyphosate. Control of common lambsquarters, waterhemp, volunteer corn (described previously), and velvetleaf following postemergence applications of glyphosate could be described as ranging from extremely effective to highly erratic. Weed size, application rate, and myriad other variables almost certainly influenced the level of weed control achieved, but suffice it to say that the efficacy of glyphosate against several weed species has declined. More and more weed control practitioners discovered that morningglory species can be difficult to control with glyphosate alone, and several posed questions about which tankmix partners can help address this weakness.

## Late-Season Observations

Cursory observations made during weed collection campaigns late in the 2006 season suggested that waterhemp, marestail, volunteer corn, giant ragweed, and shattercane were (depending on location) the most frequently encountered weed species overtopping soybean canopies. Waterhemp generally has held this distinction in past seasons, but several other species vied for this infamous status at the end of 2006. Hophornbeam copperleaf, although not visible above the soybean canopy, nonetheless was very

prevalent in many harvested corn and soybean fields of central and south-central Illinois.

There were scattered reports of delayed soybean maturity that appeared to follow late-season applications of glyphosate. Typically, soybean treated with late "clean-up" applications, made close to the R2 or R3 stage, exhibited a delay in maturity (some described the symptoms as similar to those of green stem) and a reduced number of pods toward the top of the plant stem. These symptoms did not occur on every field so treated, and speculation was made that some varieties may be more prone than others to these symptoms.

# Lessons from a "Quiet" 2006 Season—What Lies Ahead?

## Rust Is Here; Now What?

*Suzanne Bissonnette*

What started out as a fairly average disease scenario in the 2006 growing season certainly ended up with a bang.

Soybean rust was positively diagnosed in eight Illinois counties in 2006. It was first confirmed on October 13, 2006, on a sample collected from a soybean research plot at the U of I Dixon Springs Agricultural Research Center in Pope County. University of Illinois Plant Clinic director Nancy Pataky and USDA-ARS soybean plant pathologist Dr. Glen Hartman observed the sample and sent it to the national mycologist at USDA-ARS in Beltsville, Maryland, for positive confirmation and species verification, as indicated by the national protocol for handling of first soybean rust samples in a state. Soybean rust was then confirmed in seven additional counties—Massac, Hardin, White, Alexander, Johnson, Pulaski, and Jefferson.

So as not to test anyone's geography memory too much, for the most part the counties with confirmed soybean rust are the southernmost counties in Illinois. The distribution of rust in Illinois and other states can be seen on the national soybean rust Web site (Pest Information Platform for Extension and Education, PIPE), http://www.sbrusa.net. To see what happened in late 2006, select a date, such as October 27, 2006, on the side menu of the site.

Detection of soybean rust in southern Illinois counties in October 2006 was a serious reminder that the disease isn't going to hang out only on the Gulf Coast. Additionally, just one weather event moved the pathogen up the Mississippi River Valley, not only to southern Illinois but also as far as Lafayette, Indiana.

The finding of soybean rust in southern Illinois was not unexpected. Spore deposition models indicated the distinct probability of development of soybean rust in Illinois. Infection by soybean rust in Illinois so late in the season had no impact on our 2006 soybean crop. Information that was collected on the extent of this outbreak, however, greatly facilitates research on soybean rust and aids in the refinement of predictive models for soybean rust.

Again in 2006, Illinois had sentinel plots throughout the state to aid in the early detection of soybean rust. Thirty-nine sentinel soybean rust plots were established in the state. Most plots were soybean, but kudzu (*Pueraria lobata*), field pea (*Pisum sativum*), dry beans (*Phaseolus vulgaris*), and mung beans (*Vigna radiata*) were also observed and sampled. Double-cropped soybean sentinel plots also were planted in southern Illinois. Cooperators were the University of Illinois, University of Illinois Extension, and Southern Illinois University. Plots were located throughout Illinois on research stations and on commercial and private fields. Plots were sampled weekly during the season and analyzed by personnel at the University of Illinois Plant Clinic. Results of samples and crop progress were reported on the PIPE national Web site. The plots were funded by a combination of grant monies from the USDA Risk Management Agency (RMA), Illinois Soybean Association, Illinois Department of Agriculture, and the North Central Soybean Research Program.

Anticipation of soybean rust and participation in the sentinel plot program resulted in documentation of the disease progress of other foliar soybean diseases in the state, as well. Several foliar diseases were observed

including Septoria brown spot, frogeye leaf spot, bacterial blight, bacterial pustule, and downy mildew. Samples were incubated and verified at the University of Illinois Plant Clinic. These other foliar diseases are not new to Illinois; however; documentation of trends and the spread of foliar diseases was eye opening, particularly with regard to the extent of bacterial blight this season.

Information on soybean rust, rust management, fungicide recommendations, and monitoring can be found through our soybean rust Web sites, http://soyrust.cropsci.uiuc.edu and http://www.soybeanrust.org, as well as through the national USDA Web site, http://www.sbrusa.net/, which also has additional information on good farming practices documentation and insurance documentation requirements through RMA.

Numerous other online and printed resources are available to aid in soybean scouting and disease management, including

- the news release series at http://www.ipm.uiuc.edu/fieldcrops/soybeans/diseases.html;
- in-season articles in *the Bulletin*, http://www.ipm.uiuc.edu/bulletin;
- fungicide spray recommendations fact sheet, updated on our crop science Web site, http://soyrust.cropsci.uiuc.edu/index.cfm
- North Central IPM Center's soybean rust fact sheets, http://www.ncipmc.org/alerts/soybeanrust.cfm
- NCR 504 scouting brochure, http://www.aphis.usda.gov/publications/plant_health/content/printable_version/SBR_IDcard_11-04.pdf.

Soybean producers and scouts should have

- a field crop scouting guide (*Field Crop Scouting Manual*, U of I Extension publication number X880d); and
- the reprinted and updated soybean disease pocket guide (*Pocket Guide to Soybean Diseases*, U of I Extension publication number C1380).

Also, new and specifically for soybean rust are

- a disease assessment tool (*Soybean Rust Assessment Tool*, U of I Extension publication number X881); and
- a hand lens for soybean rust scouting endeavors (folding pocket magnifier, 20X, U of I Extension item number X882).

(University of Illinois Extension resources for soybean rust can be ordered online at http://www.PublicationsPlus.uiuc.edu or by calling 800-345-6087.)

Also, a new *Extension Report on Plant Disease* #1002, "Characteristics of Fungicides for Field Crops" (http://www.ag.uiuc.edu/~vista/abstracts/a1002.html) is an excellent resource when making decisions about using fungicides.

As you make your scouting and management plans for next season, remember that part of our early detection plan in Illinois includes pre-screening of soybean foliar samples for rust. In Illinois, a specialized section of our University of Illinois Digital Distance Diagnostics Imaging (DDDI) system to aid in early detection of Asian soybean rust has been in place since 2004 for you to take advantage of quick sample pre-screening. Our DDDI system is essentially an online plant clinic, and, with regard to soybean rust, our goal is rapid pre-screening and early detection of rust infected plants. Samples can be submitted to the University of Illinois DDDI system at your county Extension unit office. The results of soybean rust pre-screening via DDDI are available within a few hours. If the DDDI pre-screening appears suspect, a plant sample is submitted to the U of I Plant Clinic for verification.

In 2006, rust was not the only source for end-of-the-season troubles. Green stem in soybean continues to present harvest and yield concerns. Green stem symptoms can be a result of "green stem syndrome," which still has no known cause, or can be a symptom of bean pod mottle virus infection. Seedling and root diseases of soybean also continue to be an issue for producers. Low-quality seed led to some germination problems in 2006. Because stem and pod diseases again impacted soybean in many areas late in 2006 seed quality should be considered for the 2007 season. Cold germination tests for low-quality seed lots are more reliable indicators of performance than warm germ tests for questionable seed lots.

Corn and wheat made it through the season relatively unscathed by serious disease in 2006. Increasing levels of stalk rots were an issue in some areas of the state, particularly where injury from soilborne insects and drought were issues. Of particular concern were Diplodia stalk and ear rot and Fusarium and anthracnose stalk rots. In southern Illinois, late-season gray leaf spot and southern rust were evident. Diseases of wheat last year were mainly caused by viruses associated with aphids

and some fungal leaf blights. Scab was not a big problem this past season.

So, our best plant disease lesson from the "nearly quiet" 2006 growing season was that preparation, training, pre-screening, and vigilance really did work to detect soybean rust. Let's keep in perspective that rust is a disease that can be managed with appropriate and timely fungicide applications. And remember that monitoring does take a more diligent effort than we have been accustomed to for soybean production.

# Lessons from a "Quiet" 2006 Season—What Lies Ahead?

## Nematode Management

*Terry L. Niblack*

2006 was a pretty good year for corn and soybean, with lots of big, beautiful root systems and little evidence of widespread disease. However, those big, beautiful root systems suggest that there was plenty of food for root-feeding nematodes. On average, nematode populations increased enormously in both soybean and corn in 2006. This increase will have an impact on 2007, especially for those who choose not to rotate crops.

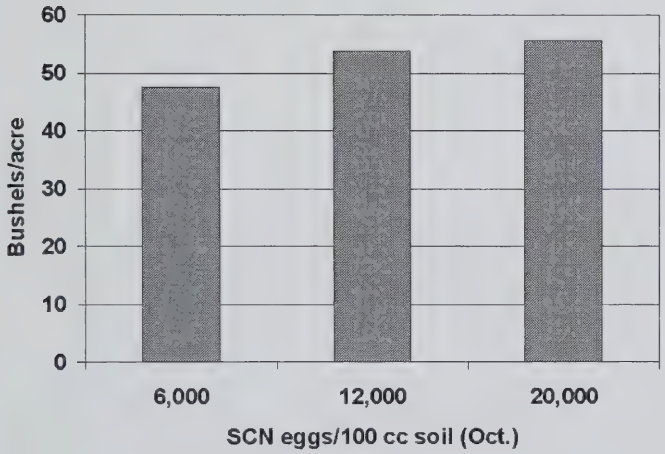


**FIGURE 1 • The number of SCN eggs/100 cc soil from samples taken at harvest, compared with the yield of soybeans from the sampled plots. All samples and yield measurements were taken from different areas of the same field planted to the same SCN-susceptible soybean variety. The egg numbers represent the final SCN population density measured in the same plots shown in Figure 2.**

### Nematology 101: The Background

Unlike the populations of many insects and pathogens, a population increase of nematodes during the current year may not affect yields. For most nematode–host pairs, yield is dependent on the number of nematodes present at planting. Nematodes present at planting are the ones that infect the developing seedlings, and, if infection is high enough, root growth will be restricted, affecting every following growth stage and eventually causing decreased yields. For example, the data in Figure 1 show the soybean cyst nematode (SCN) population densities in different areas of the same field, according to samples taken at harvest. The obvious conclusion from looking at this chart is that SCN populations *increase* yields—the higher the number of eggs, the higher the yield. However, the real relationship is revealed with data from the same field, sampled in April about 2 weeks before planting, shown in Figure 2—higher SCN populations at planting *decrease* yields.

One other lesson to take from Figures 1 and 2 is that if an SCN-susceptible variety is planted, then the lower the SCN population at planting, the higher it will be at harvest. Because of those big, beautiful root systems mentioned previously—more food, more nematodes. The relationship is shown in Figure 3.

What all of this means is that nematode populations will be higher in 2007 than they were in 2006.

### SCN in 2006

According to the calls I received and reports I heard from around the state in 2006, two things commonly happened in SCN-infested fields this year:

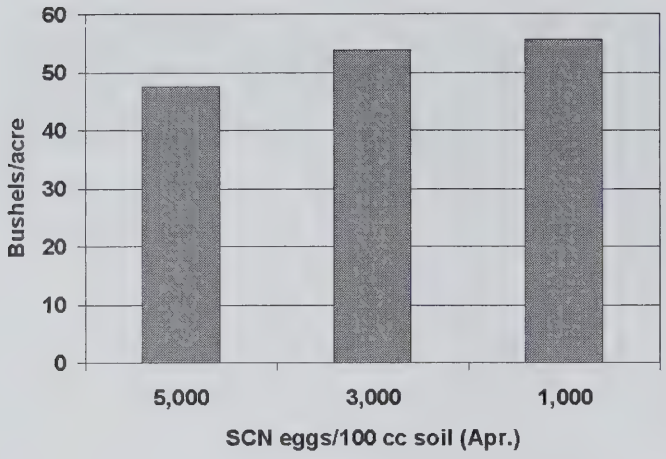


**FIGURE 2 • The number of SCN eggs/100 cc soil from samples taken at planting, compared with the yield of soybeans from the sampled plots. All samples and yield measurements were taken from different areas of the same field planted to the same SCN-susceptible soybean variety. The egg numbers represent the initial SCN population density measured in the same plots shown in Figure 2.**

- No symptoms were seen in heavily infested SCN fields except when other seedling diseases also were present. There may or may not be any specific interaction between SCN and other seedling diseases, but the stresses of excess moisture and nematode infection resulted in plenty of circular patches of stunted, yellow plants with rotting root systems, reflecting areas of standing water. In areas without short periods of standing water, very few fields had symptoms of SCN infestation, except in southern Illinois.
- Many soybean producers are discovering that their "SCN-resistant" soybeans are suffering yield loss caused by SCN. This could be the result of two things that are not mutually exclusive: first, the variety may not be resistant; and, second, the SCN population may have adapted to resistance.

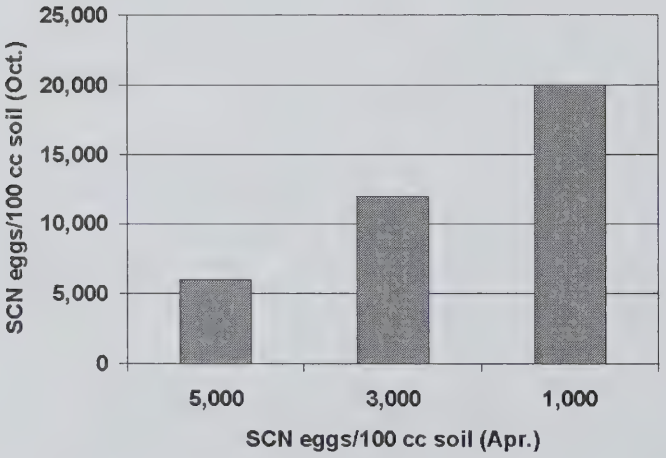


**FIGURE 3 • The relationship between number of SCN eggs at planting and number of SCN eggs at harvest (from the data presented in Figures 1 and 2) shows that SCN populations tend to be higher at harvest in plots that had lower numbers at planting.**

Based on our 2005–2006 survey, we know that 84% of the soybean fields in Illinois are infested with SCN, and we also know that more than 75% of those SCN populations already have adapted at some level to the resistant varieties we have available. Soybean producers should make an extra effort to keep an eye on the SCN populations in their fields—and to choose soybean varieties carefully. The Variety Information Program for Soybeans (VIPS, http://web.aces.uiuc.edu/VIPS) database can be an enormous help in that regard.

## Corn in 2006

In 2006, for the very first time, more soil samples from cornfields than from soybean fields were submitted to the University of Illinois Nematology Lab for analysis. This was an alarming development, suggesting we need to ramp up our educational and scouting efforts for corn nematodes. Remember that "corn nematodes" can refer to any of several different nematode species (unlike SCN). The symptoms usually are completely nonspecific (yellowing, stunting) and may be associated with root rotting.

As in previous years, we strong recommend that cornfields be sampled routinely for nematodes because the problems seem to be increasing in frequency each year. We nematologists in the Corn Belt think there are three main reasons why corn nematode problems are increasing:

- The new tools being used in IPM programs may actually be increasing nematode problems. The shift away from soil insecticides to neonicotinoid seed treatments or to genetically engineered hybrids may allow nematode populations to increase more than they were able when soil insecticide use was more widespread.
- The increase in no- or minimum-till production allows the build-up of nematode species that are sensitive to soil disturbance.
- The increase in corn-on-corn production will definitely affect the nematode populations, in a positive way for nematodes but in a negative way for corn production.

*All* corn fields have plant-parasitic nematodes in them. That does not mean that all cornfields suffer yield loss caused by nematodes, but it will pay off in the long run to know which nematodes are in each field and how their populations change over time. Sampling once every 3 years of corn (6 years in a corn–soybean rotation) is a good standard practice that should be encouraged.

## Outlook for 2007

Lessons from the past show that seasons with good growing conditions contribute to bumper crops of nematodes for the next season. Nematode management should not be at the bottom of the list for production concerns in 2007.

# Lessons from a "Quiet" 2006 Season—What Lies Ahead?

## Insect Management

*Kevin L. Steffey and Michael E. Gray*

Insect and mite pests of Illinois field crops were numerous and active in 2004 and 2005, so we were due for a "quieter" year with respect to insect pest problems. In general, insect pest numbers were fewer and insect activities were reduced in 2006, with some exceptions. However, there were enough significant occurrences and issues in the insect world of 2006 that an overview should provide ample opportunities for improving our understanding and implementation of insect management strategies.

This report is a synopsis of insect management issues in Illinois and some other areas of the Midwest in 2006, with some explanations for what happened and some prognoses for 2007. We refer you to articles published throughout the year in *the Bulletin* (http://www.ipm.uiuc.edu/bulletin) for more detailed discussions of each of the issues described in this report. For ease of discussion, the synopsis is separated by crop, although some pests were present in more than one crop (e.g., Japanese beetle).

This report does not cover in significant detail all of the insect management issues addressed by Illinois producers in 2006. In fact, a caveat about the report is necessary. A review of articles published in *the Bulletin* during the 2006 growing season revealed that crop development and insect situations varied considerably among regions (northern, west central, east central, and southern) of Illinois. So, some of the information discussed in this report will be representative of some areas and not necessarily representative of others. Nevertheless, an overview should provide insight for insect management issues that arise in localized areas or are more widespread in 2007.

### Insects and Corn Production, 2006

Despite generally cooler and wetter conditions in 2006 than in 2005, corn planting got off to another early start in 2006, especially in western counties. The accumulation of growing degree days (GDD) in April was above average, so corn emergence and development generally were quite good. Although emergence of corn was compromised somewhat in some areas by dry soils (western Illinois) and heavy rains in late April and early May, early-season growing conditions for corn were good. Consequently, early-season subterranean insect pests caused few problems. There were numerous reports of large numbers of white grubs in the spring, but there were very few reports of injury caused by the grubs. We know now that most of the white grubs observed in the spring were Japanese beetles.

The numbers of black cutworm moths captured in pheromone traps scattered throughout Illinois were larger in 2006 than they had been in several preceding years. Not surprisingly, there were more reports of economic cutting damage caused by black cutworms in 2006 than in several preceding years, including some small pockets of heavy infestations. Reports of unacceptable control of black cutworm larvae with the neonicotinoid seed treatments (especially Poncho 250) were relatively common.

The numbers of reports of severe corn rootworm larval damage and large numbers of western corn rootworm adults were considerably fewer in 2006 than in 2005. However, some fields were very badly damaged by corn rootworm larvae in 2006, especially in corn planted after soybeans. The range of the variant western corn rootworm

continued to expand slowly into mid-southern counties in 2006. Several fields of corn planted after soybeans along the I-70 corridor were severely damaged by corn rootworm larvae. Although we did not conduct a formal survey of corn rootworm larval injury in 2006, we became aware of significant rootworm larval injury in fields as far south as Bond County. As the range of the variant western corn rootworm expands, the use of rootworm control products will increase accordingly. And, as we stated last year, the use of yellow sticky traps to monitor for western corn rootworm adults in soybean fields falls far short of the effort needed to make well-informed decisions about rootworm management.

Herculex RW corn hybrids (HxRW) (event DAS-59122-7, Cry34Ab1/Cry35Ab1) was commercially available for the first time in 2006. Also for the first time, we were able to compare the efficacy of HxRW corn hybrids and YieldGard Rootworm (YGRW, event MON 863, Cry3Bb1) corn hybrids in our standard corn rootworm control trials located near DeKalb, Monmouth, Perry, and Urbana. Results from these trials are discussed in detail in the paper Transgenic Corn Rootworm Hybrids: Assessing Performance in a Variant Western Corn Rootworm Arena, printed elsewhere in these proceedings. Suffice it to say that the results from corn rootworm control trials located near Urbana revealed that the variant western corn rootworm posed some challenges for transgenic Bt corn hybrids in 2006.

Pollination again was threatened in 2006 by extremely large numbers of Japanese beetles. This recurring pest will be discussed in more detail in this paper in the section "Insects and Soybean Production, 2006."

In 2005, western bean cutworm moths were captured in pheromone traps in several counties, especially in northwestern Illinois, and as far east as Will County. In 2006, we increased our vigilance for western bean cutworm, a pest that has continued to spread eastward in the Corn Belt. With the help of University of Illinois Extension personnel and Pioneer Hi-Bred International agronomists, we established an extensive network of western bean cutworm traps in almost every county of Illinois. Entomologists from several other states also established western bean cutworm pheromone traps, and all of the capture information was reported on an Iowa State University–sponsored Web site, http://www.ent.iastate.edu/trap/westernbeancutworm. Western bean cutworm moths were captured in many counties in Illinois and Wisconsin for the first time, and also in some counties in Indiana, Michigan, Missouri, and Ohio. Details regarding this trapping effort and more information about management of the western bean cutworm are discussed in the paper Western Bean Cutworm and the Invasion of Illinois Corn: It's Like *Déjà vu* All Over Again, printed elsewhere in these proceedings.

Similar to occurrences in 2005, the "corn insect season" in 2006 ended with many reports of infestations by ear-attacking insects. There was a tendency by many people to attribute insect injury on corn ears to western bean cutworms. However, on close inspection, the culprits causing injury to the ears were usually corn earworms or fall armyworms. Accurate identification of these three ear-attacking corn insect pests will be crucial for developing appropriate insect management plans.

We also observed large densities of second-generation European corn borers in several areas of Illinois late in the season, especially in western counties. Results from our annual survey of second-generation European corn borers are presented in Table 1. Population densities (number of borers per 100 plants) increased noticeably in many counties from 2005 to 2006. Interestingly, the statewide average number of second-generation European corn borers per 100 plants in Illinois in 2006 (23.24) was lower than it was in 2005 (34.4). However, the average percentage infestation of corn plants was 24.2 in 2005 and 33 in 2006. Relatively large densities of second-generation European corn borers were evident in the West and West Southwest crop reporting districts (73.77 and 76.88 corn borers per 100 plants, respectively). Of the 498 fields surveyed, 244 (49%) of the fields had 0% infestation of European corn borer larvae, whereas 75 (15%) of the fields had between 76% and 100% infestation of European corn borer larvae (27 of 498 fields [5.4%] had 100% infestation).

## Insects and Corn Production, 2007

Some events in the corn insect world in Illinois probably seem preordained:

- The distribution of the variant western corn rootworm probably will continue to expand southward and westward in 2007.
- The western bean cutworm likely will gain more of a foothold in Illinois in 2007.
- Japanese beetles likely will threaten pollination in many areas of Illinois in 2007, although predicting where is not easy.

**TABLE 1 • Results of the 2006 fall survey for second-generation European corn borer larvae.**

| Counties[1] and Crop Reporting Districts | Percentage of plants infested, 2001 | European corn borer larvae per 100 plants |
|---|---|---|
| Bureau | 26 | 25.6 |
| Jo Daviess | 12 | 25.2 |
| Mercer | 9 | 23.0 |
| Ogle | 1 | 0.0 |
| Whiteside | 4 | 3.6 |
| Winnebago | 10 | 12.8 |
| Northwest | 10 | 15.03 |
| DeKalb | <1 | 0.4 |
| Kendall | 6 | 8.8 |
| LaSalle | 28 | 29.6 |
| McHenry | 17 | 19.8 |
| Will | 14 | 5.4 |
| Northeast | 13 | 12.8 |
| Adams | 81 | 131.8 |
| Fulton | 43 | 80.4 |
| Knox | 24 | 23.4 |
| McDonough | 15 | 30.4 |
| Schuyler | 35 | 63.2 |
| Warren | 34 | 113.4 |
| West | 39 | 73.77 |
| Logan | 25 | 48.8 |
| Macon | 32 | 25.4 |
| McLean | 21 | 34.2 |
| Peoria | 36 | 53.0 |
| Woodford | 42 | 59.8 |
| Central | 31 | 44.24 |
| Champaign | 22 | 8.0 |
| Iroquois | 10 | 10.2 |
| Livingston | 12 | 31.8 |
| Vermilion | 22 | 22.8 |
| East | 17 | 18.2 |
| Calhoun | 40 | 67.4 |
| Christian[2] | 35 | 28.8 |
| Greene | 63 | 104.0 |
| Madison | 44 | 99.2 |
| Montgomery | 50 | 105.0 |
| Morgan | 57 | 124.0 |
| Pike | 44 | 39.6 |
| Sangamon | 38 | 47.0 |
| West Southwest | 46 | 76.88 |
| Clark | 57 | 77.2 |
| Coles | 25 | 22.2 |
| Crawford | 31 | 40.2 |
| Effingham | 30 | 40.2 |
| Marion | 24 | 4.6 |
| Shelby[3] | 30 | 35.8 |
| East Southeast | 33 | 36.70 |
| Jackson | 0 | 0.0 |
| Monroe | 10 | 9.6 |
| Pulaski-Alexander | 0 | 0.0 |
| Washington | 20 | 21.8 |
| Southwest | 8 | 7.85 |
| Franklin | 2 | 0.0 |
| Massac | 0 | 0.0 |
| Saline | 16 | 10.4 |
| Wayne | 11 | 13.4 |
| White | 35 | 22.4 |
| Southeast | 13 | 9.24 |
| STATE | 33 | 23.24 |

[1]Unless otherwise indicated, 10 randomly selected fields were sampled in each county.

[2]17 randomly selected fields were sampled.

[3]11 randomly selected fields were sampled.

However, none of these events is surefire. There are many factors that cause insect populations to ebb and flow over time, and these factors (most often weather) can change any forecasts we make. Nevertheless, plans for management of corn insects in 2007 likely have been made by most corn growers, so an overview is worthwhile.

## Management of Corn Insects in 2007

The number of tools for insect control available to corn producers continues to increase. Many producers will continue to use soil-applied insecticides for control of soil-inhabiting insects, especially corn rootworm larvae, and many producers will continue to rely on seed-applied insecticides (e.g., Cruiser, Poncho) for control of subterranean insects. However, the efficacy of seed-applied insecticides against corn rootworm is not reliable, and the efficacy against some secondary insect pests (e.g., black cutworms) was called into question in 2006.

The percentage of corn acres planted to transgenic Bt corn for rootworm control will increase once again. YGRW and

HxRW corn hybrids both will be planted in 2006, and we assume that Syngenta's Agrisure RW (event MIR604, mCry3Aa) corn hybrids also will be commercially available in 2007. Although we still have much to learn about the use of transgenic corn for rootworm control, reports of its efficacy are mostly very positive. Nevertheless, some questions about the impact of transgenic corn on rootworm development and behavior linger. Incidents of significant injury to the roots of transgenic corn late in the summer (i.e., August) must continue to be investigated.

In addition to the transgenic Bt corn hybrids for control of rootworms, YieldGard Corn Borer, Herculex I, and Agrisure CB corn hybrids provide protection against European and southwestern corn borers. Herculex I also will control black cutworms and western bean cutworms. We anticipate more acres of these types of Bt corn will be planted in Illinois because of concerns about European and southwestern corn borers and about western bean cutworms. A lot more acres of "stacked" corn hybrids (i.e., corn hybrids with transgenic traits for control of corn rootworms and corn borers and for glyphosate resistance or tolerance) also will be planted in 2007. These corn hybrids seem to have everything most growers would need for insect and weed management. However, their widespread use without implementing the recommended and regulated resistance management strategies could result in serious consequences.

## Insects and Soybean Production, 2006

Soybean production got off to a much slower start than corn production in 2006. As a result of rainfall in late April and early May, less than 50% of the soybean acres had been planted by mid-May. Soybean development in 2006 was generally slower and later than in 2005.

There were few insect problems in soybeans in Illinois in 2006. The biggest threat was posed by enormous numbers of Japanese beetles defoliating soybeans in July. The largest populations of Japanese beetles occurred in southern Illinois, where many fields were treated twice for control of the insect. Scattered areas throughout central Illinois also had extremely large numbers of Japanese beetles. People likened driving through swarms of Japanese beetles to driving through a hail storm. Fortunately, the standardized percentage defoliation thresholds for all chewing insects (30% defoliation before bloom, 20% defoliation during bloom through pod fill) are reliable thresholds for Japanese beetles.

Throughout the year, we heard reports of large numbers of bean leaf beetles in other midwestern states, especially Iowa, Minnesota, and Wisconsin. However, although there were a few pockets of large numbers of bean leaf beetles in Illinois, infestations of bean leaf beetles were not widespread. In addition, we have not had the incidence of bean pod mottle virus (vectored by the bean leaf beetle) in Illinois that soybean producers in Iowa have experienced recently.

Since the discovery of the soybean aphid in the Midwest in 2000, soybean insect management has not been the same. This insect has captured our attention like no other insect pest in soybeans in the Midwest.

Soybean aphids began to show up early (mid-June) in soybean fields in Illinois in 2006, but densities of this insect built up relatively slowly during the summer and reached near-threshold levels (250 aphids per plant) only very late in the season. Most people indicated that few natural enemies were observed. When winged soybean aphids began leaving soybean fields in search of their overwintering host (buckthorn), a network of suction traps in the Midwest began capturing some of the winged aphids. We have learned from past experience that the numbers of aphids captured in suction traps in the fall may have some bearing on the potential for soybean aphid outbreaks the following year. When the numbers of aphids captured are high, there is potential for large infestations of soybean aphids the following year. When the numbers of aphids captured are low, there is less of a threat of large infestations of soybean aphids the following year. However, the presence or absence of natural enemies (e.g., multicolored Asian lady beetle) and the weather play significant roles in determining soybean aphid numbers during any given year.

Based on the flight of soybean aphids in the fall of 2006, the prospects for infestations of soybean aphids are relatively good for 2007. The numbers of winged soybean aphids captured in suction traps in the Regional Soybean Aphid Suction Trap Network (http://www.ncpmc.org/traps/index.cfm) were particularly large in Indiana. In addition, the every-other-year cycle of soybean aphids (i.e., high densities in odd years, low densities in even years) seems to suggest that we should remain vigilant in 2007.

## Insects and Soybean Production, 2007

The focus of insect management programs for soybeans in 2007 will justifiably be on soybean aphids, with bean

leaf beetles and Japanese beetles also receiving attention. In fact, with an increasing amount of data indicating that seed-applied insecticides (e.g., Cruiser, Gaucho) effectively control early season bean leaf beetles and delay the onset of heavy infestations of soybean aphids, we anticipate that more soybean producers will rely on these insecticidal seed treatments as part of their overall insect management program. We still are not convinced that the insecticidal seed treatments are cost effective for soybeans, but the added insurance against insect injury is attractive to many producers.

The continued concern about the occurrence of Asian soybean rust in Illinois will encourage many producers to scout soybean fields regularly and frequently, an activity that should improve decision making for insect management. However, we believe there will be some incentives for soybean producers to mix insecticides with either fungicides or herbicides (e.g., Roundup) or both to "control" all pests at once. Under most circumstances, this mixing of pesticides is unnecessary, and the widespread application of so many pesticides could have unintended consequences. We urge carefully planned decisions for anyone assessing the need for any of these pesticides for soybean pest management in 2007.

## One Final Note—Aphids in Alfalfa and Wheat, Too

Some aphid species were more noticeable than usual in both alfalfa and wheat fields, so their mention in this paper is one way to offer a little forewarning for next year. Fortunately, aphids have many natural enemies, and aphid populations are very susceptible to weather extremes. But these aphid species should be added to the list of more commonly occurring insect pests in alfalfa and wheat, just in case.

In alfalfa, both the pea aphid (*Acyrthosiphon pisum*) and the cowpea aphid (*Aphis craccivora*) occurred in unusually large numbers in some alfalfa fields in Illinois in 2006. The pea aphid occurs in alfalfa fields in Illinois every year, but usually at very low levels. And their numbers are usually held in check by natural enemies. The cowpea aphid, on the other hand, is a relatively recent addition to the list of potential insect pests of alfalfa in Illinois, and its repeated occurrence in alfalfa fields over the past few years bears watching. Both of these insects use their piercing mouthparts to suck fluids from alfalfa plants, and large numbers of these aphids can cause yield loss. The cowpea aphid is a greater threat to alfalfa production than the pea aphid.

In wheat, large numbers of bird cherry-oat aphids (*Rhopalosiphum padi*) were discovered in many fields in the spring of 2006. This aphid species is not uncommon and frequently is observed in wheat fields in Illinois. Bird cherry-oat aphids can vector the barley yellow dwarf virus.

# Soybean Rust: The First Three Years

*Glen Hartman*

This paper provides an update of the current situation of the occurrence of soybean rust (*Phakopsora pachyrhizi*) in the United States, specifically in Illinois in 2006, and an overview of some of the research activities. Soybean rust was reported in the continental United States in Louisiana in the fall season of 2004 (Schneider et al. 2005). Since then, rust was reported in 15 other states (http://www.sbrusa.net) including Illinois in 2006 (Hartman et al. 2007). The first report of the disease occurring on another host in the United States was on kudzu in Quincy, Florida, in 2004 (Harmon et al. 2005). The introduction of the rust fungus into the continental United States was thought be carried via Hurricane Ivan, which hit the U.S. mainland in September 2004 (http://www.ceal.psu.edu/ivan04.htm).

In 2005, the fungus was first reported in Florida (http://www.sbrusa.net), where it was believed to survive the winter on kudzu that remained green below the frost line. At the end of 2005, rust was reported in nine states (Kentucky, North Carolina, and Texas were new reports). In 2006, the fungus was again first found in Florida and was reported from Virginia to Texas and from Florida to Illinois in 255 counties in 15 states as of November 6, 2006 (http://www.sbrusa.net). Although most of the occurrences were reported late in the season, the spread of rust in 2006 was greater than 2005.

Specifically in Illinois, rust was found in eight counties in 2006. The first report was in Pope County (Hartman et al. 2007). Between this first sample (October 10, 2006) and the last sample (October 22, 2006), there were 2,176 leaf samples from 18 counties representing 70 fields. Samples were considered positive for rust if urediniospores were observed under a dissecting microscope. A few of these samples also were tested with a molecular assay and found positive for the fungus. Of the 70 fields, 30% had rust finds representing a total of 93 rust positives or Samples were considered positive for rust if urediniospores were observed under a dissecting microscope. A few of these samples also were tested with a molecular assay and found positive for the fungus. Of the 70 fields, 30% had rust finds representing a total of 93 rust positives, or 4% of the leaf samples collected. The number of uredinia ranged from 1 to 66 uredinia per leaflet.

Since the introduction of soybean rust in the United States, there has been an increase of research activity. This started soon after the first report of rust in Hawaii in 1994. A soybean rust workshop was held in 1995 that brought together researchers in the United States who had experience with rust and laid the foundation for subsequent research direction for soybean rust research in the United States (Sinclair and Hartman 1995). Before soybean rust hit the continental United States, a review in 2003 outlined the importance of the disease and evaluated the risk of rust to the U.S. soybean crop (Miles et al. 2003a). The following sections summarize some of the research in the United States since 2004. This is not a comprehensive review; instead, it highlights what has been published in three main areas of research that includes pathogen biology, host resistance, and fungicide management.

## Biology of *Phakopsora pachyrhizi*

### *Urediniospore Survival*

It is well known that fungal spores are particularly sensitive to ultraviolet (UV) wavelengths of solar radiation. In a study conducted jointly between scientists in the United States and in Paraguay, urediniospores were exposed to natural sunlight for different durations (Isard et al. 2006). Measurements of total solar irradiance (0.285–2.8 μm) predicted spore germination as much as UV measurements did (0.295–0.385 μm). Spores exposed to doses of solar ($\geq$ 28 MJ $m^{-2}$) and UV radiation ($\geq$1 MJ $m^{-2}$) did not germinate. The proportions of the spores that germinated were a linear function of solar irradiance ($R^2$ = 0.83). The relationship between spore viability and exposure to solar radiation is important to the soybean rust aerobiological model that provides North American soybean growers decision support for managing soybean rust (http://www.sbrusa.net). Further work on spore germination from spores collected from fields indicated that germination was as low as 1% and up to 99%, depending on the time and location of the collection (Beck et al. 2006).

### *Movement of Spores*

Three locations were monitored for spore movement from epidemics at various stages of development using rotorods and passive traps for 6 to 10 days each in 2005 (Beck et al. 2006). Based on spore counts from rotorods, spore release increased after leaves dried, peaked during midday, then tapered off toward the evening. Rainfall events reduced spore release for a 24- to 48-hour period. Spores enumerated on passive trap slides indicated that spores dispersed in the direction of prevailing winds at lower than expected rates (3 of 22 total observation days). Further research on monitoring and predicting spore movement and viability is critical to the development and use of accurate forecasting systems.

### *Evaluation of Isolates*

Except for USDA-ARS Fort Detrick containment facilities located at Frederick, Maryland (Bonde and Peterson 1995), there has been little effort to compare a world collection of *P. pachyrhizi* isolates. One recent study (Bonde et al. 2006) compared the virulence of *P. pachyrhizi* isolates from Asia and Australia and *P. meibomiae* from Puerto Rico and Brazil, collected as much as 30 years earlier, with isolates of *P. pachyrhizi* from Africa or South America collected in 2001. In greenhouse tests, susceptible reactions to *P. pachyrhizi* generally resulted in tan-colored lesions containing 1 to 14 uredinia varying greatly in size within individual lesions. On these same genotypes, resistance was typified by 0 to 6 small uredinia in reddish brown to dark brown lesions. *Phakopsora meibomiae*, a less aggressive rust pathogen, produced reddish brown to dark brown lesions with 0 to 7 uredinia, regardless of soybean genotype. This kind of research explains the virulence diversity of this pathogen and may explain the lack of durability in soybean lines identified with resistance. Further work on virulence diversity of U.S. isolates is in progress at the NSRC under a USDA-APHIS and Illinois Department of Agriculture permit.

### *Telia*

One of the questions in the United States was whether the fungus could produce telia. In the fall of 2005, telia were diagnosed based on visual observation followed by PCR confirmation on leaves of kudzu in central Florida (Harmon et al. 2006). Telia were noted as dark brown to black flecks on the abaxial leaf surface intermingled with abundant tan to light brown uredinia. From 200 leaflets, 143, or 72%, had telia. The number of telia ranged from a few scattered telia per leaflet (1 per $cm^2$) to many (73 per $cm^2$). Telia were approximately the same diameter as uredinia but were appressed to the leaf surface and pigmented. The importance of telia, teliospores, and basidia remains elusive because no alternate host has been found. To date, telia have been reported to occur only in Florida.

### *Host Range*

The host range of the soybean rust fungus is known to be broad (Sinclair and Hartman 1995). Native legume species in the United States have not encountered *P. pachyrhizi*. Several studies were conducted in 2005 to evaluate the host range of the fungus. In the field (Quincy, Florida), leaves of *Phaseolus coccineus* (scarlet runner bean), *P. lunatus* (lima bean), and *P. vulgaris* (kidney bean) had rust lesions when grown adjacent to a rust-infected soybean field (Lynch et al. 2006). Uredinia counts ranged from 2 to 43 per 2-$cm^2$ area of leaf samples. Additional hosts were discovered after being evaluated under greenhouse containment facilities at Fort Detrick (Lynch et al. 2006). Further work is in progress under field conditions to determine what native legumes may be hosts for *P. pachyrhizi*.

**TABLE 1 • Rust survey from Illinois counties starting with samples taken from October 10 through October 22, 2006.**

| County | No. of fields sampled[1] | Percentage of fields with rust[2] | No. of leaves sampled[3] | No. of leaves with rust[4] | Percentage of leaves with rust[5] |
|---|---|---|---|---|---|
| Alexander | 7 | 43 | 279 | 2 | 0.7 |
| Edwards | 2 | 0 | 59 | 0 | 0 |
| Franklin | 1 | 0 | 68 | 0 | 0 |
| Gallatin | 7 | 0 | 181 | 0 | 0 |
| Hardin | 2 | 100 | 61 | 15 | 25 |
| Hamilton | 1 | 0 | 24 | 0 | 0 |
| Jackson | 1 | 0 | 45 | 0 | 0 |
| Jasper | 2 | 0 | 89 | 0 | 0 |
| Jefferson | 3 | 33 | 50 | 11 | 22 |
| Johnson | 9 | 78 | 238 | 14 | 6 |
| Knox | 1 | 0 | 45 | 0 | 0 |
| Madison | 5 | 0 | 100 | 0 | 0 |
| Massac | 7 | 14 | 216 | 15 | 7 |
| Pope | 6 | 50 | 119 | 28 | 24 |
| Pulaski | 5 | 20 | 179 | 6 | 3 |
| Saline | 1 | 0 | 25 | 0 | 0 |
| Union | 2 | 0 | 78 | 0 | 0 |
| White | 5 | 20 | 148 | 1 | 0.7 |
| Williamson | 3 | 0 | 172 | 0 | 0 |
| **Totals/Means[6]** | **70** | **30** | **2176** | **93** | **4** |

[1]Two of these fields represent kudzu sites (Madison and Massac counties) and one clover (Jasper County), and two represent experimental plots (Pope County).

[2]Percentage of fields in a county with rust (number of fields positive/total number of fields sampled*100).

[3]Total number based on sporulating uredinia.

[4]Total number of leaves (leaflets) sampled in each county.

[5]Percentage of leaflets with rust (leaflets positive/total leaflets sampled*100).

[6]Total number of fields, leaflet samples, and number with rust; mean percentage of fields and leaflets with rust.

## Host Resistance

### *Soybean Germplasm*

Some of the early screening results and the genetics of resistance from previous decades were reviewed recently (Hartman et al. 2005). One of the recent objectives of the USDA-ARS research on soybean rust was to evaluate the USDA Soybean Germplasm Collection located at the University of Illinois. These soybean accessions were evaluated for resistance to *P. pachyrhizi* in the ARS Fort Detrick containment facilities. There were 3,512 out of 16,595 accessions screened that were selected for a second round of evaluation, and, of those, 805 lines were selected as potential resistant sources for further evaluations (Miles et al. 2006). Some of these lines have been screened under field conditions in several locations, including in Attapulgus, Georgia, in 2005 and Paraguay in 2006, and at multiple locations in the United States during the 2006 and 2007 summer seasons. In addition, a number of these lines have been crossed and are being

used for breeding, mapping, and genetic analysis (Hyten et al. 2007).

### *Non-Soybean*

Some additional resistance sources have been identified in wild perennial relatives (Hartman et al. 1992). In more recent studies, intersubgeneric hybrids have been created between soybean and *Glycine tomentella*. Amphiploid hybrid lines (2n = 118) were the result of this hybridization, and, when tested at the ARS greenhouse containment facility at Fort Detrick, the amphiploid hybrid clones retained the resistance that had been found in the G. *tomentella* parent (Patzoldt et al. 2006). Re-instituting the backcross procedure, while testing for resistance at every generation, could move the resistance gene(s) from G. *tomentella* to cultivated soybean. This research is ongoing and involves several research groups located at the NSRC.

## Fungicide Evaluations

### *Fungicide Testing*

Fungicide testing for control of soybean rust started in 2003 through a USDA program. The testing sites were located where rust was a problem, including Paraguay, South Africa, and Zimbabwe. Early reports of fungicide efficacy was compiled in 2003 (Miles et al. 2003b). In addition to fungicide efficacy tests, fungicide application technology and timing of fungicides have been investigated both in the United States and in Paraguay.

### *Efficacy Studies*

These experiments were completed in Paraguay, South Africa and Zimbabwe from 2003 to 2006. The studies tested different fungicides using two and three applications. The first application started 50 to 69 days after planting (DAP), followed by a second application approximately 20 days after the first, and the third application approximately 20 days after the second. Results showed that almost all fungicides controlled rust compared to the nonfungicide treatment, with yields often greater in fungicide plots than nonfungicide plots (Miles et al. 2005a–c; Mueller et al. 2005a). In some locations, the difference between the two-application program and the three-application program was also significant, and these differences showed a trend where the residual activity differs among the products. In other locations in other years, trends varied depending on the onset and severity of rust.

### *Effect of Timing of Fungicide Applications*

Timing of fungicide applications may be critical in managing soybean rust and may, if used effectively, reduce the number of applications needed for economic benefit. Trials were conducted in Paraguay (three locations) and in the United States (four locations) (Mueller et al. 2005b). In Paraguay, all three locations were infected with soybean rust; in two locations, rust significantly impacted yield. Trials in the United States had no soybean rust in 2005 but did in 2006. Treatments in each field included applications with triazole (Folicur), strobilurin (Headline), or a triazole-strobilurin combination (Quilt) applied at various times and a nonsprayed control. In Paraguay, yields in two locations were significantly greater than the control for all treatments. Data from the 2006 U.S. locations with rust are currently being compiled, but, in 2005 without rust, all but one treatment had significantly greater yield than the control at one location, and there was no statistical difference between the control and most treatments at two other locations.

## Acknowledgments

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## References

Beck, L.F., M.R. Miles, T.A. Steinlage, and G.L. Hartman. 2006. Urediniospore release and escape from rust-infected soybean fields. In Proceedings of the National Soybean Rust Symposium, November 29–December 1, 2006, St. Louis, MO.

Bonde, M.R., and G.L. Peterson. 1995. Research at the USDA-ARS Containment Facility on soybean rust and its causal agent, pp. 12–18. In Sinclair, J.B., and G.L. Hartman (eds). Proceedings of the Soybean Rust Workshop, August 9–11, 1995. University of Illinois at Urbana-Champaign, College of Agricultural, Consumer, and Environmental Sciences, National Soybean Research Laboratory, Urbana, IL.

Bonde, M.R., S.E. Nester, C.N. Austin, C.L. Stone, R.D. Frederick, G.L. Hartman, and M.R. Miles. 2006. Evaluation of virulence of *Phakopsora pachyrhizi* and *P. meibomiae* isolates. *Plant Disease* 90:708–716.

Harmon, C.L., P.F. Harmon, T.A. Mueller, J.J. Marios, and G.L. Hartman. 2006. First report of *Phakopsora pachyrhizi* telia on kudzu in the United States. *Plant Disease* 90:380.

Harmon, P.F., M.T. Momol, J.J. Marios, H. Dankers, and C.L. Harmon. 2005. Asian soybean rust caused by *Phakopsora pachyrhizi* on soybean and kudzu in Florida (doi:10.1094/PHP-2005-0613-01-RS). *Plant Health Progress* June 2005.

Hartman, G.L., R.A. Hines, C.D. Faulkner, T.N. Lynch, and N. Pataky. 2007. Late season occurrence of soybean rust caused by *Phakopsora pachyrhizi* on soybean in Illinois. *Plant Disease* (in press).

Hartman, G.L., M.R. Miles, and R.D. Frederick. 2005. Breeding for resistance to soybean rust. *Plant Disease* 89:664–666.

Hartman, G.L., T.C. Wang, and T. Hymowitz. 1992. Sources of resistance to soybean rust in perennial *Glycine* species. *Plant Disease* 76:396–399.

Hyten, D.L., G.L. Hartman, R.L. Nelson, R.D. Frederick, V.C. Concibido, and P.B. Cregan. 2007. Map location of the *Rpp1* locus that confers resistance to *Phakopsora pachyrhizi* (soybean rust) in soybean. *Crop Science* (in press).

Isard, S.A., N.S. Dufault, M.R. Miles, G.L. Hartman, J.M. Russo, E.D. DeWolf, and W. Morel. 2006. The effect of solar irradiance on the mortality of *Phakopsora pachyrhizi* urediniospores. *Plant Disease* 90:941–945.

Lynch, T.N., J.J. Marios, D.L. Wright, P.F. Harmon, C.L. Harmon, M.R. Miles, and G.L. Hartman. 2006. First report of soybean rust–caused *Phakopsora pachyrhizi* on *Phaseolus* species in the United States. *Plant Disease* 90:970.

Miles, M.R., R.D. Frederick, and G.L. Hartman. 2006. Evaluation of soybean germplasm for resistance to *Phakopsora pachyrhizi* (doi 10.1094/PHP-2006-0104-01-RS). *Plant Health Progress*, January 2006.

Miles, M.R., G.L. Hartman, and R.D. Frederick. 2003a. Soybean rust: Is the U.S. crop at risk? APSnet feature, June 2003. (http://www.apsnet.org/online/feature/rust).

Miles, M.R., G.L. Hartman, and C. Levy. 2005a. Control of soybean rust in an indeterminate cultivar at the Gwebi Variety Testing Center, Zimbabwe, 2004–05. *F&N Tests* 61:FC004.

Miles, M.R., G.L. Hartman, and C. Levy. 2005b. Control of soybean rust in a determinate cultivar at the Rattray Arnold Research Station, Zimbabwe, 2004–05. *F&N Tests* 61: FC003.

Miles, M.R., G.L. Hartman, C. Levy, and W. Morel. 2003b. Current status of soybean rust control by fungicides. *Pesticide Outlook* 14:197–200.

Miles, M.R., G.L. Hartman, N.C. van Rij, S. Tweer, E.D. du Preez, and K.F. Lawrance. 2005c. Evaluations of fungicides for control of soybean rust in the cultivar 'Prima 2000' near Cedara, South Africa, 2004–05. *F&N Tests* 61:FC002.

Mueller, T.A., C.A. Bradley, C.D. Chesrown, C.H. Koger, E.R. Walker, W. Morel, M.R. Miles, and G.L. Hartman. 2005b. Response of soybean to timing of fungicide applications in the presence and absence of *Phakopsora pachyrhizi*. In National Soybean Rust Symposium Proceedings, November 14–16, 2005, Nashville, TN.

Mueller, T.A., M.R. Miles, G.L. Hartman, and W. Morel. 2005a. Evaluation of fungicides for the control of soybean rust at Bella Vista, Paraguay, 2004–2005. *F&N Tests* 61:FC007.

Patzoldt, M.E., R.K. Tyagi, T. Hymowitz, G.L. Hartman, and R.D. Frederick. 2006. Soybean rust resistance derived from *Glycine tomentella* in amphiploid hybrid lines and derived fertile soybean lines. *Crop Science* (in press).

Schneider, R.W., C.A. Hollier, H.K. Whitman, M.E. Palm, J.M. McKemy, J.R. Hernandez, L. Levy, and R. DeVries-Paterson. 2005. First report of soybean rust caused by *Phakopsora pachyrhizi* in the continental United States. *Plant Disease* 89:774.

Sinclair, J.B., and G.L. Hartman (eds). 1995. Proceedings of the Soybean Rust Workshop, August 9–11, 1995. University of Illinois at Urbana-Champaign, College of Agricultural, Consumer, and Environmental Sciences, National Soybean Research Laboratory, Urbana, IL.

# Integration—The Key to Managing Fusarium Head Blight (FHB = Scab) in Wheat

*Marcia McMullen*

Fusarium head blight (FHB) of wheat, commonly called head scab, is a fungal disease that continues to cause yield and quality loss in all classes of wheat across most regions of the United States, with billions of dollars lost to producers and the wheat industry in recent epidemic years (McMullen et al. 1997; Nganje et al. 2004; Cowger and Sutton 2005). The disease also often results in the presence of a fungal mycotoxin byproduct called DON (deoxynivalenol). U.S. food industry standards for DON and recent stricter guidelines for DON in wheat exports to Europe and Japan make control of this disease even more important. The disease and the DON levels must be reduced to prevent further losses in wheat acreage and small grain industries.

The primary causal fungus of the disease, *Fusarium graminearum*, not only causes head scab in small grains but also causes stalk rot and ear rot in corn. In wheat, the results of FHB infection are yield losses, lowered test weight, increases in damage, reduced market grade, and possible presence of the DON mycotoxin, which further reduces market price or makes the grain unmarketable. Infection in wheat primarily occurs at the flowering period of the crop, but the fungus can continue to colonize the grain head through early dough stage. Disease development and severity are primarily dependent on rainfall or high humidities at flowering and post-flowering of the wheat crop.

Because producers cannot predict or control environmental conditions that may occur at this critical growth stage, other management strategies are needed. A number of management strategies have been demonstrated to reduce FHB and DON, including use of fungicides, crop rotation, tillage, and tolerant cultivars (Sutton 1982; Bai and Shaner 1994; Stack 1999). Recent research has provided more information about these strategies.

Fungicides can be used effectively to reduce FHB. In tests of more than 50 fungicides or fungicide combinations in Europe, reductions in FHB severity averaged between 55% and 60% with the best treatments (Mesterhazy 2003). In the United States, uniform fungicide trials conducted across wheat classes and multiple states have resulted in FHB severity reductions averaging 40% to 60% and DON reductions averaging 26% to 38% (Hershman and Milus 2003). Availability of an FHB disease forecasting Web site that provides risk information for 22 states, including Illinois, has been beneficial in helping producers make fungicide decisions. The address for this Web site is http://www.wheatscab.psu.edu.

Rotational studies have shown the influence of previous crops on this disease. In Indiana, it was shown that spore production of the fungus was about two times higher in a wheat field with corn as previous residue compared to an adjacent wheat field on soybean residue (Shaner and Buechley 2000). Rotations with corn, wheat, and soybean in Minnesota (Salas and Dill-Macky2005) showed that FHB severity was highest with corn as the previous crop, compared to a previous crop of wheat or soybeans. These same authors also demonstrated that incorporation of the infected residue also reduced subsequent FHB severity. Obst et al. (1997) demonstrated that corn in the rotation and the tillage practice following corn had large impacts on DON levels.

Considerable effort among plant breeders has resulted in great improvement in cultivar reaction to FHB in all wheat classes. Dr. Fred Kolb, a wheat breeder with the

University of Illinois at Urbana-Champaign, is presenting information at this conference on response of current soft red spring wheat cultivars to FHB. In North Dakota, a spring wheat cultivar called Alsen, which has a Sumai-3 source of resistance to FHB, was released in 2001 and by 2004, occupied 37% of North Dakota spring wheat acreage. In 2005, another cultivar was released with several sources of FHB resistance.

However, under severe epidemics, an individual strategy used alone, or even use of two strategies, cannot reduce disease severity and DON to levels required by the grain industry. For example, in 2005, when environmental conditions were extremely favorable for FHB in the Dakotas and Minnesota, very susceptible spring wheat or winter wheat cultivars that were grown on soybean ground—and even treated with fungicides—still had high yield loss and high DON. *In 2005, it became very clear that single-based strategies for managing FHB in wheat could not be successful in very favorable environments. A combination of strategies, each building on the other, is required for achieving the best management of FHB and for obtaining quality grain.*

Table 1 provides one example of how a combination of practices reduced FHB severity and DON levels in research trials in North Dakota in 2005, a year when environmental conditions were extremely favorable for the disease. Each practice alone would not have been sufficient to achieve the relative low DON level. Additional research on the additive, or synergistic, effects of management practices are currently being evaluated through cooperative, multi-state projects of the U.S. Wheat and Barley Scab Initiative.

## References


Bai, G., and G. Shaner 1994. Scab of wheat; Prospects for control. *Plant Disease* 78:760–766.

Cowger, C., and A. Sutton. 2005. The southeastern U.S. Fusarium head blight epidemic of 2003. *Plant Health Progress* (http://www.ars.usda.gov/research/publications/publications.htm?SEQ_NO_115=171662).

Hershman, D.E. and E.A. Milus. 2003. Analysis of 2003 uniform wheat fungicide trials across locations and wheat classes, pp. 76–80. In Proceedings of the 2003 National Fusarium Head Blight Forum, Bloomington, MN. December 13–15, 2003. U.S. Wheat and Barley Scab Initiative, Michigan State University, East Lansing, MI.

McMullen, M., R. Jones, and D. Gallenberg. 1997. Scab of wheat and barley: A re-emerging disease of devastating impact. *Plant Disease* 81:1340–1348.

Mesterhazy, A. 2003. Control of Fusarium head blight of wheat by fungicides, pp. 363–380. In Leonard, K., and W. Bushnell, (eds). *Fusarium Head Blight of Wheat and Barley*. APS Press, St. Paul, MN.

Nganje, W., S. Kaitibie, W.W. Wilson, F.L. Leistritz, and D.A. Bangsund. 2004. *Economic Impacts of Fusarium Head Blight in Wheat and Barley: 1993–2001.* NDSU Agribusiness and Applied Economics Report No. 538, July 2004, 53 pp.

Obst, A., J. Lepschy-Von Gleissenthall, and R. Beck. 1997. On the etiology of Fusarium head blight of wheat in south Germany. *Cereal Research Communications* 25:699–704.

Salas, B., and R. Dill-Macky. 2005. Effect of residue management and host resistance on the epidemiology of Fusarium head


**TABLE 1 • Influence of management practices on Fusarium head blight (FHB) and deoxynivalenol (DON), North Dakota State University, across two North Dakota eastern research locations, Fargo and Prosper, 2005.**

| FHB management practice | FHB reduction % | Actual FHB severity index[1] % | DON reduction % | Actual DON ppm |
|---|---|---|---|---|
| None | 0 | 40 | 0 | 10 |
| **Rotation alone:** soybean residue instead of wheat | 50 | 20 | 50 | 5 |
| **Rotation + Variety:** Alsen (MR) rx instead of Reeder (S) rx | 60 | 8 | 60 | 2 |
| **Rotation + Variety + Fungicide:** Folicur fungicide at flowering instead of untreated | 60 | 3.2 | 40 | 1.2 |

[1] FHB severity index = incidence of tillers with symptoms × head severity on infected tillers/100.

blight, pp. 144–146. In Proceedings of the 2005 National Fusarium Head Blight Forum, Milwaukee, WI, December 11–13, 2005. U.S. Wheat and Barley Scab Initiative, Michigan State University, East Lansing, MI.

Shaner, G., and G. Buechley. 2000. Sampling spores of *Fusarium graminearum*, pp. 182–186. In Proceedings of the 2000 National Fusarium Head Bight Forum, Erlanger, KY, December 10–12, 2000. U.S. Wheat and Barley Scab Initiative. Michigan State University, East Lansing, MI.

Stack, R.W. 1999. Fusarium head blight: Return of an old problem. APSnet feature, May 1999 (http://www.apsnet.org/feature/FHB).

Sutton, J.C. 1982. Epidemiology of wheat head blight and maize ear rot caused by *Fusarium graminearum*. *Canadian Journal of Plant Pathology* 4:195–209.

# Fungicides on Hybrid Corn: Yield Impact of Foliar Disease Control

*Gary P. Munkvold*

Foliar diseases have been recognized as an economic problem on commercial corn for more than a century, and fungicides have been available for their control for several decades. However, throughout much of the history of hybrid corn production, fungicides were not recommended and were very rarely used for foliar disease control. Interest in this form of foliar disease management in corn heightened in 1993–1994, when two events took place: an unusually severe outbreak of common rust (*Puccinia sorghi*) swept across the central Corn Belt, causing significant yield losses in hybrid corn and completely destroying some fields planted to inbreds for seed production (Munkvold and Yang 1995); and propiconazole (Tilt fungicide, Syngenta Crop Protection, Greensboro, NC) was the first systemic fungicide approved for use on corn.

During the past 13 years, the corn fungicide situation has evolved rapidly; a number of new active ingredients have received approval, and the use of fungicides in corn seed production has become a routine practice. This evolution was spurred initially by the demonstration in 1993 of very significant yield increases with the use of propiconazole to control common rust, but it also was fueled by the emergence during the 1990s of gray leaf spot (*Cercospora zeae-maydis*) as a significant economic problem in corn grown in Illinois, Indiana, Iowa, and Nebraska. Most fungicide use on corn in subsequent years has been targeted toward common rust or gray leaf spot, although northern leaf blight (*Exserohilum turcicum*) is not uncommon and occasionally southern rust (*Puccinia polysora*) or northern leaf spot (*Bipolaris zeicola*) can be targets.

While the 1990s saw wide adoption of fungicide use in corn seed production, fungicides in commercial hybrid corn were not widely adopted. The reasons for this differential adoption are clear: the relatively low value of corn grain compared to seed and the relatively lower susceptibility of hybrids in general to yield loss from foliar diseases, compared to inbreds commonly used as seed parents.

To use fungicides profitably in hybrid corn production, it has been necessary to more carefully assess the risk of yield loss. Assessing this risk has only recently been aided by the development of modeling approaches for the prediction of disease severity (Paul and Munkvold 2004, 2005). These tools need to be coupled with information about the relationship between disease severity and yield loss in order to make effective decisions about using fungicides. There is a continual need for up-to-date information on these relationships as new fungicide active ingredients continue to be approved for use on corn. The situation is complicated by the potential for direct effects of some fungicides on plant physiology, independent of disease control. This aspect will be covered elsewhere in these proceedings; this article focuses on the use of fungicides for disease control and yield benefits related to disease control.

## Decision-Making for Fungicide Use on Hybrid Corn

Fungicide decisions for hybrid corn must take into account several risk factors. Using a simple disease threshold (or economic injury level, EIL) alone is not sufficient. In most cases, economic injury levels (Pedigo 1999) have not been established for foliar diseases of corn. It can be

difficult to apply these concepts to the management of corn foliar diseases. Economic injury level calculation requires knowledge of the amount of damage (yield loss) per unit of pest population (or disease severity) and knowledge of the expected efficacy of the management input (Pedigo 1999). It is assumed that these parameters and others are known with a high level of precision, and the economic injury level is calculated as a single value, not associated with a probability. An action threshold is reached when it is estimated that actual injury will reach the EIL, and the management tactic is employed (Pedigo 1999).

Unfortunately, measurements of yield losses associated with specific corn foliar disease severity levels and measurements of yield increases attributable to fungicide applications are not precise. Damage per unit of gray leaf spot severity can vary by as much as 100% between locations or hybrids (Jenco 1995). Calculation of EIL based on predicted disease control is not practical when damage per unit injury varies to such a great extent.

Another difficulty is that, because of yield variability within experimental fields, yield increases that appear to exceed the cost of fungicide application frequently are not statistically significant. For example, Ward et al. (Ward et al. 1997, 1999) calculated that a "break-even" yield increase for fungicidal control of gray leaf spot under conditions in South Africa would be 259 kg/ha. However, they reported that, in some experiments, yield differences of more than 1,200 kg/ha were not statistically significant. Similarly, in several studies performed in the United States, the least significant yield difference among treatments was greater than (by sometimes twice as much) the break-even yield increase (Lipps and Johnson 1998, 1999; Stromberg and Flinchum 1998, 1999; Shaner and Buechley 1999). These problems create a dilemma in development of disease management recommendations. The economic justification of a fungicide application is difficult to assess when the break-even yield difference is not statistically significant. The following guidelines can be useful for increasing the likelihood that a fungicide application will be profitable.

Typically, in the central Corn Belt, only one application can be considered economically feasible on hybrids, and the best time to make the decision is when the disease is at very low levels at or near tasseling. Factors to consider in the decision about using fungicidal control include

- history of disease in the field
- previous crop
- tillage practices
- hybrid susceptibility and maturity
- planting date
- field productivity and corn prices
- fungicide and application costs
- weather patterns
- scouting observations (compared to a threshold)

### *Field History, Previous Crop, Tillage*

Fields with a history of disease problems, corn on corn fields, and minimum tillage fields are at a higher risk and more likely to benefit from a fungicide application. These three factors are all related to the potential for disease inoculum. Previous crop and tillage practices will affect the risk of diseases other than rusts. Field history is related specifically to the amount of inoculum that might be present from a previous disease outbreak, but it also relates to the potential for fields to be prone to more frequent disease outbreaks due to geography or topography.

### *Hybrid Susceptibility*

The probability of using a fungicide profitably is directly related to hybrid susceptibility. A fungicide should not be considered for moderately resistant or resistant hybrids. These hybrids are unlikely to benefit economically from an application. It may be appropriate to consider fungicides with hybrids that are in the moderately susceptible to susceptible categories.

### *Hybrid Maturity and Planting Date*

Hybrid maturity and planting date are important in relation to the timing of disease development. In most situations, later-planted fields and/or later-maturing hybrids can be more vulnerable to yield loss because they are still filling grain while disease development is peaking in the late summer. Therefore, these later fields are more likely to benefit from a fungicide application.

### *Field Productivity and Corn Prices*

When both field productivity and corn prices are higher, the cost of a fungicide is more justifiable, and this information should be considered in relation to fungicide and application costs.

### *Weather Conditions*

If you understand the optimal conditions for the diseases in your area, you can judge whether the weather or weather forecast is favorable for the disease. If temperatures are conducive and there is plenty of humidity and/or rainfall, the probability of benefiting from a fungicide application goes up.

### *Scouting Observations*

Scouting serves several purposes in relation to foliar diseases. It provides information on the timing of initial infection. The earlier the infection happens, the greater the risk of yield loss, especially for fast-moving diseases such as the rusts. Scouting also provides a measure of how quickly the disease is developing and provides the basis for timing of fungicide applications. Strict disease thresholds, however, are not precise for determining the need for a fungicide, and thresholds should be used only as one of several pieces of information in the decision. Below is a general guide to disease thresholds for hybrids differing in disease susceptibility.

- **Susceptible or moderately susceptible hybrids**—A fungicide application can be used profitably on these hybrids if the disease is present on the third leaf below the ear leaf (or higher) on 50% of the plants before tasseling.
- **Intermediate hybrids**—A fungicide application can be used profitably on these hybrids only if conditions are very favorable for the disease. This is likely if
  - the field is in an area with a history of problems with gray leaf spot or other disease;
  - the previous crop was corn, and there is 35% or more surface residue;
  - the field itself has a history of problems with gray leaf spot or other disease;
  - the disease is present on the third leaf below the ear leaf (or higher) on 50% of the plants before tasseling; and
  - the weather is warm and humid through July and August.
- **Moderately resistant or resistant hybrids**—We do not recommend using a fungicide on these hybrids.

## Yield Impact of Fungicides on Hybrid Corn

Most published data on yield benefits for fungicide applications on hybrid corn have targeted gray leaf spot. Published trials have been conducted most commonly in Virginia, Indiana, and Iowa. Studies in Indiana have focused on corn inbreds. Most reports are brief data summaries, but two more detailed studies illustrated the influence of hybrid susceptibility on the likelihood of yield loss and subsequent likelihood of economic benefit from a fungicide application.

Gorman et al. (1997) used inoculations and Tilt fungicide applications to measure the yield benefit of controlling gray leaf spot on hybrids with different levels of resistance in field trials conducted in Tennessee, Pennsylvania, Indiana, and Iowa in 1995 and 1996. They found mean yield increases of about 8.5% with Tilt applications on moderately resistant hybrids and about 14.5% on susceptible hybrids (Figure 1). The authors did not assess the profitability of the two Tilt applications. A similar study was conducted in 2004–2006 by the same author, investigating the yield increases due to control of southern corn leaf blight (*Bipolaris maydis*) with Quadris fungicide (Syngenta Crop Protection, Greensboro, NC) in Georgia. Similar results were obtained; moderately resistant hybrids did not exhibit significant yield increases, but susceptible hybrids yielded significantly higher with Quadris applications.

Munkvold et al. (2001) analyzed data from fungicide trials conducted in Iowa from 1995 to 1997 and assessed the probability of profitable fungicide use under natural infection on several hybrids differing in susceptibility to gray leaf spot. Treatments were compared using a Bayesian inference method to calculate for each experiment the probability of achieving a positive net return with one

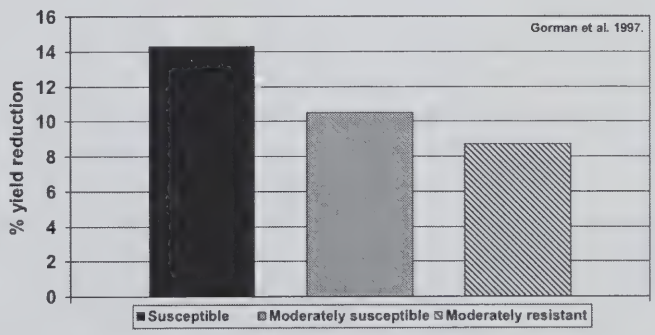


**FIGURE 1 • Yield increase resulting from gray leaf spot control in corn hybrids differing in resistance.**

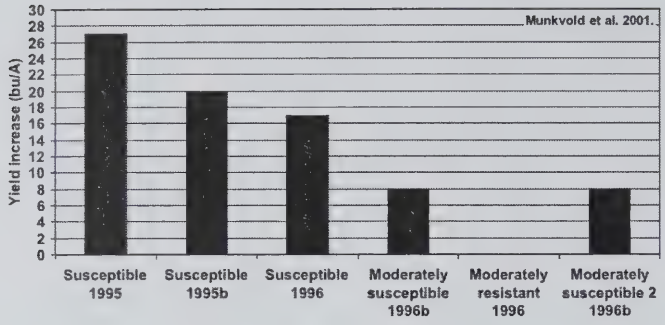


**FIGURE 2 • Yield increases from one application of Tilt fungicide to control gray leaf spot in Iowa field trials on corn hybrids differing in susceptibility in 1995 and 1996.**

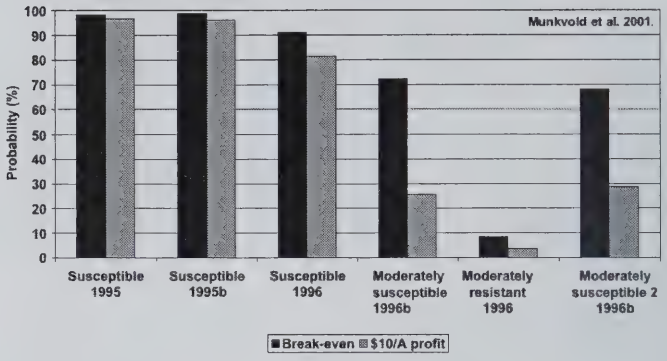


**FIGURE 3 • Probabilities of profit from one application of Tilt fungicide to control gray leaf spot in Iowa field trials on corn hybrids differing in susceptibility in 1995 and 1996.**

or two propiconazole applications, based on the mean yields and standard deviations for treated and untreated plots, the price of grain, and the costs of the fungicide applications. For one application, the probability ranged from about 0.06 to more than 0.99, and exceeded 0.50 in six of nine scenarios (specific experiment/hybrid). The highest probabilities occurred in the 1995 experiments with the most susceptible hybrid, when yield increased by 27 bu/A with a single Tilt application (Figures 2 and 3). Probabilities were almost always higher for a single application of propiconazole than for two applications. We concluded that a single application of propiconazole frequently was profitable for gray leaf spot management in Iowa, but the probability of a profitable application was strongly influenced by hybrid susceptibility. The calculation of probabilities for positive net returns was more informative than the standard approach of determining significant differences among treatments in terms of assessing the economic success of the fungicide applications.

Since those studies were conducted, the standard fungicides used on corn have moved from the triazoles, such as Tilt, to fungicides in the strobilurin family, Quadris and Headline (BASF Corp., Florham Park, NJ) or formulations combining a triazole with a strobilurin, Stratego (Bayer Crop Science, Research Triangle Park, NC) and Quilt (Syngenta). Gray leaf spot has been the most common target of fungicide applications in published studies on hybrids. In these reports, there have typically been one or two susceptible hybrids and no comparisons with moderately resistant hybrids. Studies in Iowa from 1999–2000 demonstrated yield increases of up to 20 bu/A with gray leaf spot control, and the best treatments were Tilt (1999, two applications) or single applications of Quadris (1999 and 2000) (Figure 4). Studies have been done annually in Virginia, with sometimes dramatic results. Gray leaf spot pressure is typically higher in Virginia than in the Corn Belt, and a susceptible hybrid is used to maximize differentiation of fungicide products. In the Virginia studies, in contrast to the findings in Iowa, two applications frequently result in significantly higher yields than one application. In 2001, a yield difference of more than 70 bu/A was reported (Stromberg and Flinchum 2002), and the best treatment was two applications of Headline. In 2002, the best treatment was two applications of Quadris + Tilt (similar to the current product called Quilt) (Stromberg and Flinchum 2003). In 2004, a difference of more than 70 bu/A was again reported and the best treatments were two applications of Quilt (Stromberg and Kenley 2005). In 2005, the best treatment was two applications of Headline (Stromberg and Kenley 2006) (Figure 4). In most experiments, treatments including other strobilurin products resulted in yields similar to the best treatment. In a Nebraska study in irrigated corn in 2005, yields were high in all treatments, and the

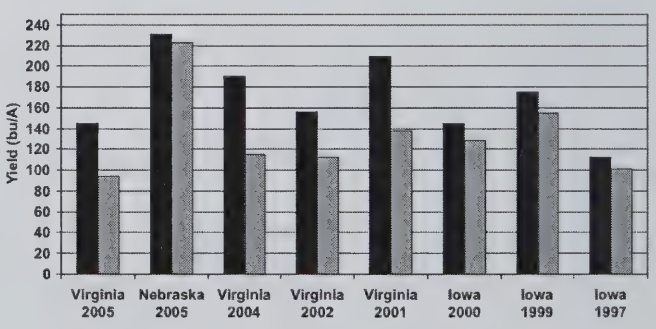


**FIGURE 4 • Yield increases due to gray leaf spot control in hybrid corn in Virginia, Nebraska, and Iowa.**

yield difference was 7 bu between the control and the best treatment (Headline), but this was not statistically significant (Figure 4) (Jackson 2006).

### *Application Timing*

The most common timing for single applications is at silking, although earlier applications can be effective if disease is developing heavily prior to silking. Second applications are usually made 2 weeks after the first application, although intervals of up to 3 weeks can be used with the current fungicides. A common question is, "How late can I start making applications and still have an economic impact on disease?" This question arises when the disease does not develop or is not noticed until some time after silking. Although there are no definitive data, a rule of thumb is that a first application made more than 2 to 3 weeks after silking has little chance of being profitable. The potential for a fungicide to protect yield is limited to how much grain filling remains to occur between the fungicide application and physiological maturity. As the plant nears maturity, the potential to protect yield diminishes, regardless of disease pressure.

## Summary

Fungicides can be used profitably to control foliar diseases on hybrid corn, but, typically, the practice is profitable only when a susceptible hybrid is grown and conditions are very favorable for disease. Several risk factors should be taken into consideration in making fungicide application decisions on hybrid corn. Decision-aid tools are being developed to help quantify the risk of yield loss and assist in making effective decisions. If applications of strobilurin fungicides have effects on corn yields independent of disease control, these effects must be measured so that they can be considered quantitatively in the cost/benefit estimation that should be the basis of fungicide application decisions.

## References


Gorman, D., B.M. Anderson, and L. Abad. 1997. Yield loss of corn hybrids with differing levels of gray leaf spot resistance, pp. 171–182. In Proceedings of the 52nd Annual Corn and Sorghum Research Conference, Chicago, IL, December 10–11, 1997.

Jackson, T.A. 2006. Evaluation of foliar fungicides on gray leaf spot of corn in Nebraska, 2005. *F & N Tests* 61:FC041.

Jenco, J.H. 1995. Epidemiology of *Cercospora zeae-maydis* on *Zea mays* in Iowa. M.S. thesis, Iowa State University. 69 pp.

Lipps, P.E., and A.L. Johnston. 1998. Control of gray leaf spot on corn with fungicides in Ohio, 1996. *F & N Tests* 53:287.

Lipps, P.E., and A.L. Johnston. 1999. Control of gray leaf spot on hybrid corn with fungicides in Ohio, 1998. *F & N Tests* 54:352–353.

Munkvold, G.P., and X.B. Yang. 1995. Crop damage and epidemics associated with 1993 floods in Iowa. *Plant Disease* 79:95–101.

Munkvold, G.P., C.A. Martinson, J.M. Shriver, and P.M. Dixon. 2001. Probabilities for profitable fungicide use against gray leaf spot in hybrid maize. *Phytopathology* 91:477–484.

Paul, P.A., and G.P. Munkvold. 2004. A model-based approach to preplanting risk assessment for gray leaf spot of maize. *Phytopathology* 94:1350–1357.

Paul, P.A., and G.P. Munkvold. 2005. Regression and artificial neural network modeling for the prediction of gray leaf spot of maize. *Phytopathology* 95:388–396.

Pedigo, L.P. 1999. *Entomology and Pest Management.* Prentice Hall, Upper Saddle River, NJ. 691 pp.

Shaner, G., and G. Buechley. 1999. Effect of fungicides on gray leaf spot, 1998. *F & N Tests* 54:354.

Stromberg, E.L., and L.E. Flinchum. 1998. Evaluation of foliar fungicides for the control of gray leaf spot disease on corn in Virginia, 1997. *F & N Tests* 53:143–144.

Stromberg, E.L., and L.E. Flinchum. 1999. Evaluation of foliar fungicides for the control of gray leaf spot of corn in Virginia, 1998. *F & N Tests* 54:359–360.

Stromberg, E.L., and L.E. Flinchum. 2002. Evaluation of foliar fungicides for the control of gray leaf spot of corn in Virginia, 2001. *F & N Tests* 57:FC91.

Stromberg, E.L., and L.E. Flinchum. 2003. Evaluation of foliar fungicides for the control of gray leaf spot of corn in Virginia, 2002. *F & N Tests* 58:FC002.

Stromberg, E.L., and C.C. Kenley. 2005. Evaluation of foliar fungicides for the control of gray leaf spot of corn in Virginia, 2004. *F & N Tests* 60:FC074.

Stromberg, E.L., and C.C. Kenley. 2006. Evaluation of foliar fungicides for the control of gray leaf spot of corn in Virginia, 2005. *F & N Tests* 61:FC061.

Ward, J.M.J., M.D. Laing, and F.H.J. Rijkenberg. 1997. Frequency and timing of fungicide applications for the control of gray leaf spot in maize. *Plant Disease* 81:41–48.

Ward, J.M.J., E.L. Stromberg, D.C. Nowell, and F.W. Nutter, Jr. 1999. Gray leaf spot: A disease of global importance in maize production. *Plant Disease* 83:884–895.

# Application Strategies to Improve Crop Health

*Robert E. Wolf*

A challenging aspect of combating crop disease is the lack of practical experience in making fungicide applications into dense crop canopies such as soybeans during the growth stages during which a disease such as Asian soybean rust may strike. Experience with disease control in heavy canopies indicates that getting the spray droplets to penetrate into the canopy would be beneficial in achieving the best coverage and in improving efficacy. However, experience also tells us that when using conventional spray systems, it can be very difficult to achieve adequate coverage into lower parts of heavy crop canopies.

This article reviews the results of multiple studies undertaken to gain insight into achieving better in-canopy deposition of crop protection fungicides. Field and laboratory experiments were conducted using conventional, electrostatic, and aerial application systems, comparing each to achieve this purpose. For each system, typical spray operation parameters were used as treatments, while comparing nozzle types, application volumes, and deposition aid products. For all trials, either water-sensitive papers or Kromekote paper was positioned near the top, middle, and bottom of the canopy to collect the spray droplets, and DropletScan was used to measure and compare the coverage differences.

The studies showed that, when using the evaluated application systems, applicators will have limited success in placing droplets into the lower parts of full-canopied soybean plants. With the conventional spray system, nozzle type had little effect but differences were measured. For the conventional and aerial trials, coverage improved with increased application volumes. The addition of deposition aids tends to improve the total amount of coverage into the lower parts of the canopy. Adding an electrostatic charge to the spray does not provide significant improvement.

The following sections provide a brief review of the various studies.

## Field-Canopy Penetration Trials

### *Conventional Sprayer in Soybeans*

Trials were conducted using a conventional field sprayer equipped with turbo flat fan and venturi flat fan nozzles, each sprayed at 5, 7.5, 10, and 12.5 gallons per acre (GPA). Comparisons were evaluated between nozzle types and among application volumes. When comparing nozzle type in the bottom of the canopy, findings show that the turbo flat fan had slightly better coverage at 5 and 10 GPA, while the venturi nozzle had more coverage at 7.5 and 12.5 GPA. With the turbo flat fan, coverage in the bottom of the canopy improved as GPA increased from 5 to 12.5. This trend was not apparent with the venturi nozzle. With both nozzle types, the most coverage was found at 12.5 GPA. When the nozzle types were averaged across all canopy locations (top, middle, and bottom), only slight differences in nozzle type were measured, with just a slight edge shown in amount of coverage by the venturi nozzle. Differences in application volume were apparent, with improved coverage shown with each volume increase.

### *Electrostatic Sprayer in Soybeans*

Trials were conducted using a conventional sprayer equipped with an electrostatic spray system. Comparisons were made between extended-range flat fan and

turbo flat fan nozzles with and without the electrostatic system turned on. Measurements were taken in three canopy locations. Differences in nozzle type were found in the top of the canopy, with little difference measured in the lower parts of the canopy. Without electrostatics, the turbo flat fan had significantly more coverage in the top of the canopy than the extended-range flat fan did. However, with electrostatics, the extended-range flat fan significantly outperformed the turbo flat- fan. When comparing electrostatic on versus off in the bottom of the canopy, small amounts of coverage were measured, with no differences measured with the extended range and a slight improvement in coverage for the turbo flat fan over the extended-range flat fan without electrostatics. No differences were seen when comparing the nozzle types at the lower canopy level. If anything, a slight decrease in coverage was found with the turbo flat fan with electrostatics. When all levels of coverage were averaged across nozzle type, the extended-range flat fan had slightly more coverage with the electrostatics on. However, with the turbo flat fan, more coverage was achieved without the electrostatics. Without electrostatics, the turbo flat fan outperformed the extended range, but with electrostatics, the extended range outperformed the turbo flat fan.

### *Aerial Sprayer in Soybeans*

Field trials were conducted using an airplane to determine the effect of increased application volume and the addition of a deposition aid on coverage in the lower parts of a soybean canopy. Volumes compared were 1 and 3 GPA with a combination of four deposition aids. The deposition-aid treatments were Preference, Placement and Preference combined, Preference and Interlock combined, and Interlock and Rivet combined. All comparisons included water and crop oil concentrates with a treatment of water and crop oil as the standard. In all comparisons except Placement and Preference, the 3 GPA application volume exhibited more lower canopy coverage when compared to 1 GPA. All deposition-aid treatment somewhat improved the coverage when compared to the water and crop oil treatment. The exception was the treatment of Placement and Preference, in which the 1 GPA treatment was significantly better than 3 GPA. In all comparisons at 3 GPA, the combination treatments of Interlock and Preference and Interlock and Rivet were best, with the Interlock and Preference showing the most coverage. When averaged across all coverage levels, the 3 GPA treatments were superior to the 1 GPA treatments, except for the Placement and Preference. Again, in all treatments averaged across the levels of coverage except for Placement and Preference at 3 GPA, the deposition-aid treatments were better than water and crop oil alone. All deposition aids at 1 GPA exhibited better coverage than water and crop oil.

## Laboratory and Field Canopy Penetration Trials—Nozzle Type in Soybeans

Laboratory and field trials were conducted to determine the effect of nozzle type on coverage in the bottom of a soybean canopy. For the laboratory trial, potted soybean plants were arranged in a dense canopy representing a drilled soybean field. At the time of the laboratory trials, the soybean plants were 25 inches tall and in the growth stage R1 to R2, with an estimated canopy fill of 90% to 95%. The second trial was conducted in a soybean field. In the latter case, the soybean plants were drilled and, at the time of the treatments, were 18 inches tall and in the growth stage R3 to R4. The canopy was estimated at 75% filled (Table 1).

Nozzle types used in the laboratory study were selected based on possible choices from selected nozzle manufacturers. The field-trial nozzle choices were selected after reviewing the results from previous trials conducted in the laboratory. Several nozzles with poor performance were

**TABLE 1 • Materials and methods for laboratory and field nozzle trials.**

| | Laboratory treatments | Field treatments |
|---|---|---|
| Target GPA[1] | 20 GPA | 20 GPA |
| Application speed | 10 mph | 10 mph |
| Boom height | 20 inches | 20 inches |
| Nozzle type | 20 configurations | 12 configurations |
| Spray solution | Tap water and NIS | Tap water, NIS, Headline |
| Soybean plant height | 25 inches | 18 inches |
| Soybean growth stage | R –R2 | R3–R4 |
| Soybean row spacing | Pots arranged as drilled | Drilled |
| Canopy condition | 90%–95% filled | 75% filled |

[1]All applications were made with a spray track machine designed for this experiment.

eliminated for the second trail. Treatments were designed to compare all the nozzle types at 20 GPA and 10 mph. The orifice size chosen was selected first to meet the flow rate requirements for the GPA and mph (0.67gallons/minute) and then for the pressure necessary to qualify for the droplet spectra desired. The droplet spectrum of 200 to 300 VMD microns was selected for these studies, and most all nozzle treatments were selected to fit this range. This range matches the American Society of Agricultural and Biological Engineers' (ASABE) Droplet Standard S-572 classification as high-fine to mid-medium–sized droplets. Nozzle manufacturers' droplet sizing charts were used to fit the nozzles for this study (Table 2).

The spray material used in the laboratory study consisted of a mixture of 500 mL (0.5 quart) of tap water and non-ionic surfactant (NIS) at 5% volume/volume. For the field trial, Headline (fungicide), to simulate an actual tank mix, was also added.

A special spray track machine was designed and fabricated to simulate actual field spraying conditions and to facilitate multiple treatments and replications. The spray track had an aluminum bar 24 feet long, with an electric motor and chain-driven sprayer boom. The electric motor was equipped with three gears that drive a chain that propelled the sprayer boom on the aluminum bar at 5, 10, and 15 mph. The electric motor was equipped with a brake to

**TABLE 2 • Treatment, nozzle, pressure, droplet spectra classification, and tank mix solution.**

| Treatment | Lab nozzle treatments[1] | Field nozzle treatments[2] | psi | Droplet spectra classification (DSC)[3] |
|---|---|---|---|---|
| 1 | XR 11006 | XR11006 | 50 | Medium |
| 2 | TT 11006 | TT11006 | 50 | Coarse |
| 3 | TT 11005 | TT11005 | 75 | Coarse/medium |
| 4 | TT 11004 | TT11004 | 95 | Medium |
| 5 | TD XR 11004 | TD XR 11004 | 115 | Medium |
| 6 | TD TT 11004 | TD TT 11004 | 115 | Medium |
| 7 | TD XL 11004 | X | 115 | Medium |
| 8 | SR 110-05 | X | 75 | Medium |
| 9 | SR 110-06 | SR 110-06 | 50 | Fine/medium |
| 10 | ER 80-06 | ER 80-06 | 50 | Medium |
| 11 | TwinCap TT 11003[4] | TwinCap TT03[4] | 50 | Medium |
| 12 | TwinCap TT 11004[4] | X | 27 | Medium |
| 13 | TwinJet 06[4] | TwinJet 06[4] | 50 | Medium |
| 14 | TJ Duo TT 03, wide[4] | X | 50 | Medium |
| 15 | TJ Duo TT 03, narrow[4] | TJ Duo TT03, narrow[4] | 50 | Medium |
| 16 | TeeJet Duo XR 03[4] | X | 50 | Medium |
| 17 | AirMix TF05[4] | AirMix TF 05[4] | 75 | Medium |
| 18 | TD TF04[4] | X | 115 | Medium |
| 19 | SR 110-03[4] | X | 50 | Medium |
| 20 | MR 110-025[4] | X | 75 | Medium |

[1]All treatments used a tank mix solution of tap water and non-ionic surfactant.

[2]All treatments used a tank mix solution of tap water, non-ionic surfactant, and Headline.

[3]Based on the ASABE S-572 droplet spectra classification system and nozzle manufacturers' charts/suggestions.

[4]Twin or double orifice nozzle configurations.

stop the spray boom at the end of track. The system was powered in the field by a field generator. The spray bar was supported in the field on tripods and could be adjusted to different heights. The whole setup could be moved to different locations in the field by sliding the tripod along the ground. The sprayer boom had two nozzles spaced at 20 inches that were controlled by a solenoid valve operated by a battery-operated remote control. The pressure for each treatment was created by using a $CO_2$ cylinder. All the treatment solutions were placed in 500 mL (0.5 quart), high-pressure spray bottles and attached to the spray boom to complete the trials. All treatments were randomly assigned, with two replications.

**TABLE 3 • Laboratory treatment means for percent area coverage.**

| Treatment[1] | Nozzle | Percent area coverage |
|---|---|---|
| 1 | XR 11006 | 1.9 cd[3] |
| 2 | TT 11006 | 5.1 a |
| 3 | TT 11005 | 2.6 bcd |
| 4 | TT 11004 | 4.2 ab |
| 5 | TD XR 11004 | 5.1 a |
| 6 | TD TT 11004 | 3.5 abcd |
| 7 | TD XL 11004 | 3.4 abcd |
| 8 | SR 110-05 | 3.5 abcd |
| 9 | SR 110-06 | 3.9 abc |
| 10 | ER 80-06 | 4.3 ab |
| 11 | TwinCap TT 11003[2] | 2.7 bcd |
| 12 | TwinCap TT 11004[2] | 2.9 abcd |
| 13 | TwinJet 06[2] | 3.5 abcd |
| 14 | TJ Duo TT 11003, wide[2] | 1.6 d |
| 15 | TJ Duo TT 11003, narrow[2] | 3.4 abcd |
| 16 | TeeJet Duo XR 11003[2] | 2.4 bcd |
| 17 | AirMix TF05[2] | 3.7 abcd |
| 18 | TD TF04[2] | 4.2 ab |
| 19 | SR 110-03[2] | 3.1 abcd |
| 20 | MR 110-025[2] | 3.6 abcd |
| | LSD | 2.29 |

[1]All treatments used a tank mix solution of tap water and non-ionic surfactant.

[2]Twin or double orifice nozzle configurations.

[3]Different letters indicate significance at $P = 0.10$.

**TABLE 4 • Field treatment means for percent area coverage.**

| Treatment[1] | Nozzle | Percent area coverage |
|---|---|---|
| 1 | XR11006 | 8.1 ab[3] |
| 2 | TT11006 | 6.0 b |
| 3 | TT11005 | 10.0 a |
| 4 | TT11004 | 8.5 ab |
| 5 | SR 11006 | 7.5 ab |
| 6 | ER 8006 | 9.0 ab |
| 7 | TD XR04 | 7.3 ab |
| 8 | TD TT04 | 7.9 ab |
| 9 | Twinjet 06[2] | 6.3 b |
| 10 | TJ Duo TT03, narrow[2] | 6.4 b |
| 11 | AirMix TF 05[2] | 7.1 ab |
| 12 | TwinCap TT03[2] | 6.7 ab |
| | LSD | 3.58 |

[1]All treatments used a tank mix solution of tap water, non-ionic surfactant, and headline.

[2]Twin or double orifice nozzle configurations.

[3]Different letters indicate significance at $P = 0.10$.

The results for laboratory treatments indicated that percent area coverage (PAC) in the lower canopy ranged from 1.6% to 5.1%, with an LSD of 2.29%. The best coverage in the lower canopy was attained with the TT11006 sprayed at 50 psi and the TD XR 11004 at 115 psi (5.1%). There was no significant difference in the top 15 nozzle treatments. The top four ranked nozzles for PAC were single nozzle orifice designs. The average PAC for the single nozzle treatments was greater than the PAC for the double nozzle designs (3.75% to 3.11%). Three of the significantly lowest coverage amounts were from double orifice designs (Table 3).

For the field treatments, PAC ranged from 6% to 10%, with an LSD of 3.58%. The best coverage in the lower canopy was attained with the TT 11005 sprayed at 75 psi (10.0%). The next closest coverage amount was delivered by the ER 8006 at 50 psi (9.0%). The lowest three nozzles, the TJ Duo TT 11003/narrow angle at 50 psi (6.7%), TwinJet 11006 at 50 psi (6.3%), and the

TT 11006 at 50 psi (6.0%) were all significantly less than the TT11005, but not any of the other nozzle treatments (Table 4).

As shown in previous research, canopy density is a major factor in controlling the amount of penetration into the lower portions. In both studies, the single nozzle designs, on average, placed more coverage into the bottom of the canopy when compared to the double nozzle designs. The double nozzles were expected to provide better lower canopy coverage. Another interesting finding was that the venturi designs at higher pressures did not perform nearly as well as the conventional nozzles at the lower pressures.

Even though differences were minimal for most treatments, the strategy to use twin or double nozzle configurations for improved lower canopy penetration is not supported by the data in these studies. Therefore, it may not be necessary to outfit spray systems with nozzles other than the conventional turbo and extended-range types. These conventional nozzle systems performed well, provided that smaller orifice sizes and higher pressures were selected. The data show that, in addition to calibrating for the increased GPA recommendations for fungicide applications, an additional step to calibrate for the proper droplet spectra classification is essential. This extra calibration step is not a common practice but, when taken, typically results in a smaller orifice used at a higher pressure. For example, in this study, the TT 11006 at 50 psi, the TT 11005 at 75 psi, and the TT 11004 at 95 psi all provided the same application volume but a different droplet spectra, resulting in different amounts of coverage in the lower canopy.

# Tillage System Effects on Root Growth and Fertilizer Placement Considerations

*R.M. Cruse*

The environment surrounding plant roots is extremely complex and variable. For example, it is not uncommon for the surface 1 to 2 inches of soil to be very dry while very wet conditions exist at deeper areas within the root zone. Surface soil temperatures may differ by 20°F or more from that observed at deeper layers within the rooting zone. A zone of compactions caused by wheel traffic may create very different conditions on one side of a crop row compared to the other side where no traffic occurs. The environmental variations occurring in the root zone tend to be much greater than those that occur above ground.

To most effectively understand crop response to fertility practices, we should understand how crop root systems respond to the soil environmental conditions. This is particularly true with conservation tillage systems, because we tend to create more soil environmental variability with conservation tillage than we do with conventional tillage systems.

## Tillage and the Soil Environment

Conservation tillage creates a different soil environment than that which commonly occurs with conventional tillage systems that use full-width soil disturbance and burial of surface plant residue. Because of surface plant residue, soil temperatures tend to remain cooler during the spring warm-up. Soil water contents tend to be higher, particularly near the soil surface. Depending on traffic patterns and tillage tools used, compaction patterns may be more prevalent. With less soil mixing, fertilizer-applied nutrients tend to become more concentrated in the zone of application.

Conservation tillage systems tend to create a more nonuniform soil environment than that which occurs with conventional tillage systems. This nonuniform condition may affect total root growth and root growth patterns. In general, total root growth in a nonuniform soil environment will be similar to that occurring in a uniform one. However, plants tend to grow a disproportionate amount of root mass in the most favorable portion of the rooting zone, reducing the quantity of roots in the zone least favorable for growth (Russell 1977). This evolved survival mechanism is called root growth compensation.

## Tillage, Root Growth, and Fertilization

Two tillage systems that have the potential to create the most nonuniform soil environmental conditions are ridge tillage and no-till. By design, the ridge system results in a warm row area and cool interrow area. Wheel traffic is ideally confined to the interrow area, creating a compacted area to one side of the row and likely an untrafficked area to the opposite side. The ridge will be drier than the interrow area. The most favorable root growth zone is in and below the ridge and in the interrow zone not compacted by wheel traffic. Fertilizer applications should be directed to the zones favoring root growth. Applications in the cool, wet interrow zone subjected to wheel traffic will likely be less efficiently used than applications to preferred root growth zones.

No-till management has the potential to create spatial variations similar to those occurring for ridge tillage, depending on how surface plant residue is managed. Clearing residue from the row zone creates a relatively warm and dry zone in the row compared to zones under the residue. This management practice favors rapid early

plant growth and root growth in the row zone area. If plant residue remains spread uniformly on the soil surface, horizontal root growth patterns will be similar to those occurring with conventional tillage, except root growth tends to be shallower. No-till conditions keep the surface soil moist for a longer period of time than conventional tillage conditions and, as a result, root growth can and does occur to a greater extent near the soil surface.

Conservation tillage practices that use a tool such as a disk or chisel plow create more uniform conditions than do ridging or no-till practices. Wheel tracks tend to be removed, at least near the surface, to a significant extent. Plant root growth as affected by soil temperature and water conditions is similar to root growth occurring with conventional tillage.

As tillage intensity decreases, fertility uniformity in the field also tends to decrease. Moldboard plowing, to exemplify, followed by secondary tillage operations mix fertilizer-applied nutrients quite thoroughly throughout the plow layer. Less intensive primary tillage operations, such as chiseling or disking, result in horizontally uniform distributions of broadcast fertilizers. However, nutrients tend to concentrate near the soil surface more than that which occurs with more intensive tillage operations. With ridge tillage or no-till, fertility tends to build in the zone of application. Banding results in zones of high fertility, assuming

- the row positions are reasonably fixed with time; and
- applications are directed to the same position annually.

Surface broadcast applications tend to result in surface-layer fertility increases, with fertility decreases in deeper layers.

Nutrient concentration zones affect root growth. Phosphate and nitrate stimulate root growth in the zones of nutrient enrichment. Potassium does not. Thus, fertilizer concentrations near the surface tend to stimulate root growth in this zone, assuming soil moisture and temperature conditions are favorable. Banding fertilizers containing phosphate or nitrogen will likely encourage root proliferation in the application zone if the tillage system does not disturb the band and if soil fertility test levels are not high or very high. The enhanced root growth resulting from nutrient concentration favors plant survival and production.

Developing bands of fertility within a field seems to be a favorable practice for soils with low fertility, particularly when application rates are not excessive. Barber (1984) indicates that fertilizer should be concentrated in roughly one third of the soil volume for maximum uptake efficiency. If application rates are high, or high soil test levels exist, placement seems to have little effect. While one subsurface band application will not result in one third of the soil volume being fertilized, repeated applications will likely result in nutrient concentration zones considerably larger than those of a single application (this assumes that the tractor driver and applicator do not perfectly match the previous year's application—an assumption normally valid for typical application).

An additional advantage of fertilizer banding is in weed control. Weeds, similar to crop plants, respond to fertility. Subsurface banded fertilizer near the plant row in a zone favorable for crop root growth favors nutrient uptake by the crop as opposed to nutrient uptake by weeds growing randomly in the field. High fertility conditions near the soil surface spread uniformly across the field seem to favor rapid early weed growth in that many weed species germinate and grow from a shallow soil depth.

## Fertility Placement Recommendations

Consider zones that may be either favorable or unfavorable for root growth when deciding on fertilizer placement options. If potentially unfavorable zones exist, avoid placement in these zones.

If you use no-till or ridge tillage for row crop production and soil test levels are not high, attempt to place fertilizer consistently in the same position. Banding may be preferable to broadcast applications. If tillage is more uniform across the field and/or if soil test levels are high, placement is less important. If small grains and/or forage crops are part of your rotation, fertilizer placement practices other than banding may be preferable.

## References

Barber, S.A. 1984. *Soil Nutrient Bioavailability*. John Wiley & Sons, New York.

Russell, R. S. 1977. *Plant Root Systems. Their Function and Interaction with the Soil*. McGraw-Hill, London.

# Why Is My Field Showing Potassium Deficiency?

*Fabián G. Fernández*

## Importance of Potassium in the Plant

After carbon, hydrogen, oxygen, and nitrogen, potassium (K) is the most abundant element in most crops (Rosolem et al. 1993; Mullins and Burmester 1999). Generally, optimal plant tissue K is in the range of 2% to 5% based on plant dry weight (Darst and Wallingford 1985). In addition, throughout the entire life cycle of most plants, this nutrient plays an important role in many physiological plant functions. Under severe K deficiency, lignification of vascular bundles is reduced, contributing to the high susceptibility to lodging (Marschner 1995). Water-use efficiency under drought conditions is enhanced by the role of K in stomatal regulation and maintenance of turgor pressure in the vacuole. Potassium has been classified as the principal inorganic solute having a key role in osmoregulation (Hsiao and Läuchli 1986). For cell extension to occur, cell wall extensibility has to increase and solute accumulation must take place to maintain osmotic potential. Cell extension—plant growth—is partially regulated by K associated with inorganic and organic acid ions (Green and Muir 1979; Mengel and Arneke 1982). The driving force of K influx in localized parts of the plant allows for the mechanical reorientation of leaves in response to light signals. This phototropic response renders plants the ability to either increase light interception to maximize photosynthesis or to avoid excess light to protect against injury caused by high light intensity (Koller 1990). In addition, K is important in regulating more than 60 enzymes that catalyze a great number of metabolic activities (Suelter 1970, 1985). Potassium is important in maintaining charge balance by counterbalancing the negatively charged ions present in the cytoplasm, increasing disease resistance, controlling phloem transport, increasing crop quality, and improving overall plant development and yield (Marschner 1995). All these physiological aspects, linked in varying degrees to K, make this nutrient a key element for sound agricultural management of intensive cropping systems.

## Understanding K in the Soil

Potassium is the seventh most abundant element in the earth's crust (Sparks and Huang 1985). Because most K is bound in the mineral form of K-feldspars and micas and some is fixed (also known as nonexchangeable or slowly available K) in interlayer regions of clays, only about 2% of the total K is in the exchangeable and solution phases (Sparks 1987). In most soils, adequate K supply to a growing crop normally requires addition of this nutrient in the form of fertilizer. However, applied K can quickly become unavailable to plants by being fixed between clay lattices or, in coarse texture or low cation exchange capacity (CEC) soils, it can be leached out of the root zone. It also can be lost by soil erosion (Figure 1). Part of the applied K will remain available to the plant, but assessing K availability is difficult because soil-phase $K^+$ (the pool from which plants obtain K) exists in a dynamic equilibrium with the other K pools, and soil and plant characteristics influence how much, where, and when K will be available or taken up.

## First, Some Things About Soil Sampling for K

The goal in collecting soil samples is to characterize the nutrient status of the soil. This does not mean that the soil test value should be viewed as an absolute value or that individual samples should necessarily yield the same

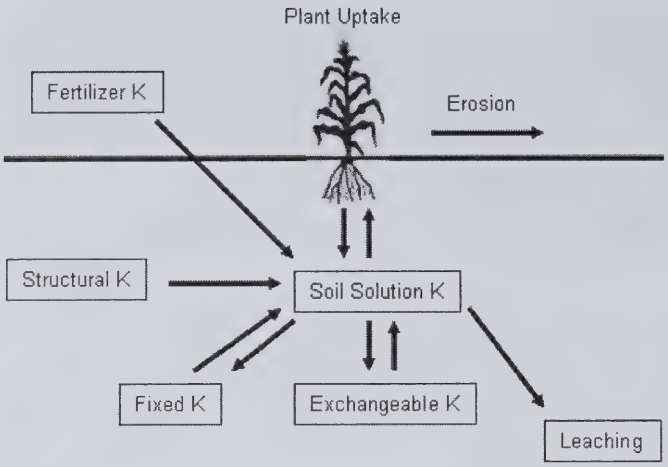


**FIGURE 1 • The potassium cycle, showing components, inputs, and losses.**

test result, but rather that, through sampling, we captured the variability present in the field. However, the results from a soil test cannot be more accurate than the accuracy of the sample obtained to characterize a field. For this reason, soil sampling must be viewed as a crucial part of soil testing and must be done carefully.

Unfortunately, the greatest source of inaccuracy in a soil test value is typically associated with the technique used to collect the sample. Prior to widespread use of fertilizers, it was relatively easy to find homogeneous levels within a field. With the adoption of fertilization, and especially where nutrients are band applied, large differences in test results can be found within a given field. Because K is mostly an immobile nutrient, under reduced soil mixing by tillage, it becomes vertically and horizontally stratified in the soil. Therefore, to adequately capture K variability in a field, the area should be divided by major units that differ in soil type, topography, past and present management, and any other major difference. Depth of sampling, adequate sampling rate, time of year for the sampling, and the type of crop to be planted should also be considered carefully when designing a soil sampling strategy.

## Factors to Consider

When, despite our best efforts to "follow the book," we see K deficiencies in our fields, it is natural to think, "What did I do wrong?" or "The lab is not doing their job right." Let us suppose that no one is to be blame (i.e., your K soil test levels are at an optimum). Then why is the crop showing potassium deficiency? Potassium availability for a crop is regulated by many factors, and the observed deficiency in the plant could be simply the indicator that some of those factors are not allowing the crop to take up all the K it needs. A discussion of some of the major factors involved in regulating K availability follows.

### *Water Availability*

Potassium reaches the root surface of a crop in three main ways: (1) diffusion: ions moving along a concentration gradient from high to low concentration points, (2) mass flow: ions being carried to the root in the convective flow of soil water originated by plant transpiration, and (3) root interception: ions are encountered by the roots as they grow into the soil. Of these three, diffusion is by far the most important mechanism of K acquisition (Table 1).

In order for $K^+$ ions to diffuse, there has to be water present in a continuum from the root surface to where the ion is present. When soils dry, pore spaces become void of water and air fills the space. This reduces diffusion by lowering the cross-sectional area for diffusion and increasing the tortuosity (or length) of the diffusion path. Although K is present in the soil under these conditions, this nutrient could become positionally unavailable to

**TABLE 1 • Relative significance of root interception, mass flow, and diffusion in supplying corn with its nutrient requirements from a fertile Alfisol silt loam (amounts are given in lb/A).**

| Nutrient | Amount needed for 150 bu/A | Approximate amount supplied by | | |
|---|---|---|---|---|
| | | Root interception | Mass flow | Diffusion |
| Nitrogen | 170 | 2 | 134 | 34 |
| Phosphorous | 36 | 1 | 2 | 33 |
| Potassium | 174 | 4 | 31 | 139 |
| Calcium | 36 | 54 | 134 | 0 |
| Magnesium | 40 | 13 | 89 | 0 |
| Sulfur | 20 | 1 | 58 | 0 |

Adapted from Barber 1995.

the crop (Barber 1995). The need for adequate supply of water to take up K was demonstrated in a greenhouse study in which soybean (*Glycine max* (L.) Merr.) was grown under two K treatments: $K^-$ and $K^+$ (80 and 164 ppm K, respectively), and two watering regimes: $W^-$ and $W^+$ (soil was allowed to dry to 55% field capacity (FC) before rewatering to 85% FC, and soil water content was maintained constant at 85% to 95% FC, respectively). Accumulation of K in the shoot was significantly increased only when sufficient water was available to take advantage of the added fertility (Figure 2) (Fernández 2006). When K was supplied without adequate water availability, the crop showed similar tissue K concentrations as those grown under a low K testing soil.

Adequate soil water content is not needed just for K diffusion. Potassium uptake is an active process; under reduced soil water availability, root activity and growth will decline and hinder K uptake. During prolonged periods of drought, K deficiencies are often seen more frequently in no-tillage or reduced tillage fields. In these tillage systems, due to little mixing of surface-applied fertilizers into the soil, K and other nutrients tend to concentrate mostly in the surface layer of the soil. This layer may be more susceptible to drying under prolonged droughty conditions compared to deeper layers of the soil. In this scenario, root growth may be more vigorous in deeper portions of the soil profile if water availability is greater. However, strong vertical stratification of nutrients with greater concentrations in the surface layer means that the deeper roots might not encounter sufficient K to supply plant needs. Fortunately, in most years, droughty conditions do not extend for a prolonged period of time, and, once rainfall replenishes water in the K-rich surface layer of the soil, K deficiencies tend to disappear.

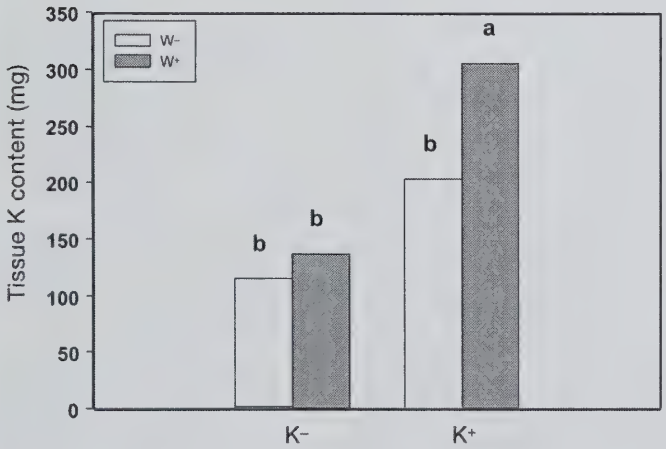


**FIGURE 2 • Mean vegetative tissue K content of individual soybean plants grown in a greenhouse pot-study.**

$K^-$ and $K^+$ represent soil K treatments with starting soil test K concentrations equal to 80 and 164 ppm K, respectively. $W^-$ and $W^+$ refer to insufficient water treatment in which soil dried to 55% field capacity (FC) before being rewatered to 85% FC and sufficient water treatment in which soil water was maintained between 85% and 95% FC, respectively. Bars with same letters are not significantly different ($P < 0.05$).

### *Oxygen Levels in the Soil*

An opposite problem to drought, but with similar impact on K acquisition, occurs when soils become saturated with water. As air in the soil pores is displaced by water, gas exchange with the atmosphere is reduced about $10^4$ times (due to lower diffusion rate of gas in water, compared to air), and oxygen levels in the soil are depleted quickly by respiring roots and soil fauna (Marschner 1995). Under these conditions, root growth and activity decline. Because K uptake is an active process, low oxygen causes a reduction in K acquisition. In fact, soil aeration has a more pronounced impact on K uptake than on other ions. Danielson and Russell (1957) showed relative uptake of $^{86}Rb$ (a counterpart for K) declines rapidly when soil oxygen levels dropped below 10%.

### *Soil Temperature*

Potassium uptake involves biological, chemical, and physical reactions. Most of these reactions require a certain temperature to provide sufficient kinetic energy to move the reaction forward. When cool soil conditions are present, it is more common to see K deficiency than when the crop is growing in warm soils. This is especially true for reduced tillage and no-tillage systems in which large quantities of crop residue left in the surface of the soil delay warm-up by reducing direct solar radiation on the soil. Low temperature can impact K uptake by reducing the ability of either the root to absorb K or of the soil to supply K to the root (Ching and Barber 1979). The ability of the root to absorb K in cool soil is reduced due to a decline in both root growth and activity. Soil K supply is also reduced under low temperatures because diffusion rates to the root and the actual rate of release of exchangeable K into the soil solution are slowed down.

### *Crop*

It is important to consider the amount, rate, and time of K uptake for different crops. For instance, K uptake

by corn (*Zea mays* (L.)) occurs rapidly between V6 and V12 and very rapidly from V12 to V18 development stages. Normally, by the middle to the end of July, this crop has taken up 100% of its K. Because of this uptake pattern, it is more common to see temporary K deficiency symptoms in corn in the early season, often in relation to cool and wet soil conditions. On the other hand, soybeans take up K over a prolonged period of time, with greater rates during the latter part of the growing season as the crop enters the reproductive (R) stages of development. Typically, soybeans will have taken up 100% of their K sometime during the end of August to middle of September.

Other important crop characteristics that can influence crop K uptake include the size of the root system and its architecture. Nutrient and water uptake are root surface area phenomena. Thus, increasing root surface area will increase K uptake. The architecture of the root can have important implications regarding the portion of the soil profile that will be exploited and the degree of competition between neighboring roots. Fibrous-rooted crops such as corn and wheat (*Triticum aestivum* (L.)) are more capable of exploiting the surface layer of the soil profile compared to tap-rooted crops such as soybeans.

Finally, plant and root age, K influx characteristics of plant roots, and root exchange capacity differences are other crop parameters that can have important impacts on K uptake.

### *Other Factors*

Any other factors that influence K availability in the soil or the ability of the root to take up this nutrient can result in K deficiencies showing up in fields testing at optimal K levels. A few of these factors are soil mineralogy and the K-supplying power of the soil, which can reduce fertilizer use efficiency; soil acidity, which can impact both nutrient availability and root activity; pathogens and pests that attack the root system or reduce crop efficiency; and soil compaction, which causes mechanical impedance for root penetration.

## References


Barber, S.A. 1995. *Soil Nutrient Bioavailability: A Mechanistic Approach*, 2nd edition. John Wiley & Sons, New York.

Ching, P.C., and S.A. Barber. 1979. Evaluation of temperature effects on K uptake by corn. *Agronomy Journal* 71:1040–1044.

Danielson, R.E., and M.B. Russell. 1957. Ion absorption by corn roots as influenced by moisture and aeration. *Soil Science Society of America Proceedings* 21:3–6.

Darst, B.C., and G.W. Wallingford. 1985. Interrelationship of potassium with cultural and management practices, pp. 559-573. In Munson, R.D. (ed). *Potassium in Agriculture*. ASA, CSSA, and SSSA, Madison, WI.

Fernández, F.G. 2006. Potassium acquisition by soybean affected by stratified soil potassium, growth stage, and soil water content. Ph.D. dissertation, Purdue University.

Green, J.F., and R.M. Muir. 1979. Analysis of the role of potassium in the growth effects of cytokinin, light and abscisic acid on cotyledon expansion. *Physiologia Plantarum* 46:19–24.

Hsiao, T.C., and A. Läuchli. 1986. Role of potassium in plant–water relations, pp. 281–312. In Tinker, B., and A. Läuchli (eds). *Advances in Plant Nutrition*, Volume 2. Praeger Scientific, New York.

Koller, D. 1990. Light-driven leaf movements. *Plant, Cell, and Environment* 13:615–632.

Marschner, H. 1995. *Mineral Nutrition of Higher Plants*, 2nd edition. Academic Press, San Diego.

Mengel, K., and W.W. Arneke. 1982. Effect of potassium on the water potential, the osmotic potential, and cell elongation in leaves of *Phaseolus vulgaris*. *Physiologia Plantarum* 54:402–408.

Mullins, G., and C. Burmester. 1999. Potassium uptake by crops during the season, pp. 123–132. In Oosterhuis, D.M., and G.A. Berkowitz (ed). *Frontiers in Potassium Nutrition: New Perspectives on the Effects of Potassium on Crop Plant Physiology*. Potash and Phosphate Institute/Potash and Phosphate Institute of Canada, Norcross, GA.

Rosolem, C.A., M.A. Bessa, and H.F.M. Pereira. 1993. Potassium dynamics in the soil and K nutrition of soybeans. *Brazilian Journal of Agricultural Research* 28:1045–1054.

Sparks, D.L. 1987. Potassium dynamics in soils, pp. 1–61. In Stewart, B.A. (ed). *Advances in Soil Science*, Volume 6. Springer-Verlag, New York.

Sparks, D.L., and P.M. Huang. 1985. Physical chemistry of soil potassium, pp. 201–276. In Munson, R.D. (ed). *Potassium in Agriculture*. ASA, CSSA, and SSSA, Madison, WI.

Suelter, C.H. 1970. Enzyme activated by monovalent cations. *Science* 168:789–795.

Suelter, C.H. 1985. Role of potassium in enzyme catalysis, pp. 337–349. In Munson, R.D. (ed). *Potassium in Agriculture*. ASA, CSSA, and SSSA, Madison, WI.

# The Perfect Corn Stand

*Emerson D. Nafziger*

Before we talk about how to get a "perfect" stand of corn, it helps to know what stand, in terms of plant numbers, we are trying to establish. This number has been a moving target for corn in Illinois, but mostly, and appropriately, the direction of that movement is up. The average plant stand recorded in Illinois by the Agricultural Statistics Reporting Service in 2006 was 28,000 plants per acre, the same as in 2005 but up about 10% since 2002 (NASS). Many producers have increased their targeted plant population in corn in recent years yet still wonder, after a year with good weather and good yields, whether they should have set the planter for higher populations than they did.

We have come to expect that yield response to plant population will vary depending on conditions. Figure 1 shows, as an example, the population responses from several Illinois locations in 2006. Such a range of responses is fairly typical, with yield continuing to increase up to 40,000 plants per acre under very good conditions (DeKalb and Urbana), to top out in the mid-30,000s and sometimes drop off at higher populations under occasionally dry conditions (Monmouth), and to remain relatively flat over a wide range under very dry conditions (Perry). In general, then, though there is a risk of losing seed costs and even some yield when conditions are poor, there seems to be little risk, and some reward, in raising plant populations into the mid-30,000s in productive soils in Illinois.

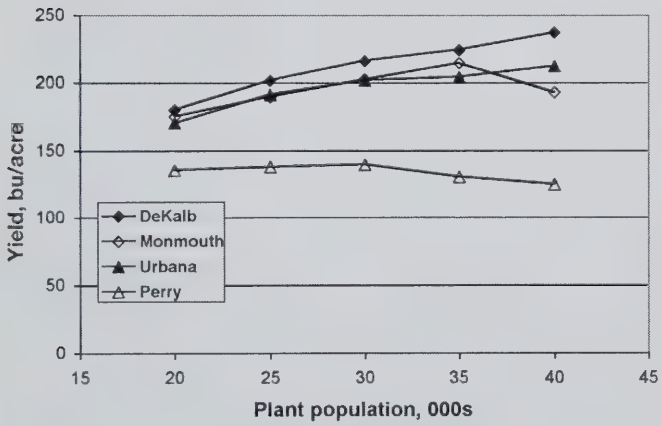


**FIGURE 1 • Corn plant population responses at four Illinois locations, 2006. The same corn hybrid (Pioneer® 34A18) was used at each location.**

One of the longest-running debates in corn production has been about the effect of uneven plant spacing on corn yields. This debate began in the 1980s, when Bob Nielsen at Purdue University started some innovative work in which he created very uneven stands and found that it reduced yields. He chose to measure plant spacing variability using the statistic "standard deviation" (SD), which increases from zero with a perfect stand to as much as 6 to 8 inches when stands are very uneven—for example, when many of the plants are present as doubles (two plants very close together) or there are many skips (missing plants) down the row. Measuring the SD requires measuring the spaces between individual plants; therefore, it is not a quick and easy measurement.

In one of our early studies done by cooperating farmers in field-scale strips in Illinois, we found that faster planting speeds increased plant spacing variability slightly but had no effect on yield (Table 1). Others have reported SD values ranging from 2 to more than 4 inches, and,

**TABLE 1 • Effect of planting speed on plant spacing and yield, averaged over on-farm trials in Illinois, 1996–1998.**

| Planting speed, mph | Standard deviation (inches) | Plant population (per acre) | Yield (bushels per acre) |
|---|---|---|---|
| 3 | 2.87 | 27231 | 152.5 |
| 5 | 2.99 | 27373 | 152.2 |
| 7 | 3.22 | 26996 | 153.1 |
| LSD 0.05 | 0.33 | NS | NS |

in a few cases, SD values as high as 6 to 8 inches have been reported. Because SD values are influenced by plant population (and vice versa), SD values above 4 or 5 inches are almost always associated with low stands, with a lot of missing plants. Exceptions might be when a serious planting malfunction occurs, with a large number of doubles and skips, even at a high population.

In a more recent study, we found that thinning plants to an even stand compared to an uneven stand had little effect on yield (Figure 2). After a number of such investigations, most agronomists now believe that, while perfectly spaced plants down the row is the ideal, there is likely to be little yield loss under the small amount of variability (SD values less than 3 inches or so) in the

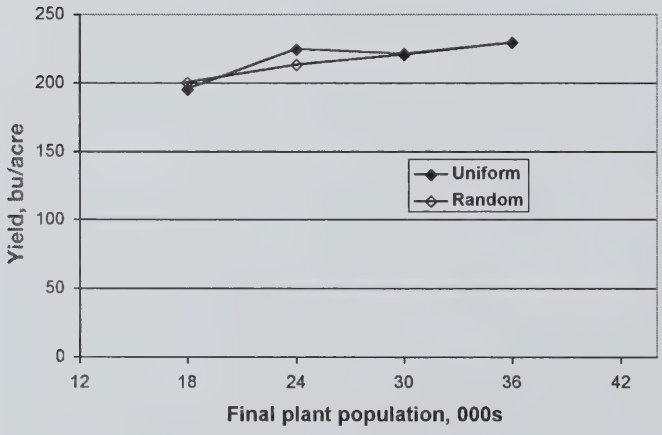


**FIGURE 2 • Effect of uniformly or randomly thinned plants on plant population response, Urbana, 2006. Standard deviation values (inches) were 3.47 (uniform, U) and 7.35 (random, R) at 18,000, 2.43 (U) and 4.42 (R) at 24,000, 2.44 (U) and 3.57 (R) at 30,000, and 2.45 inches at 36,000.**

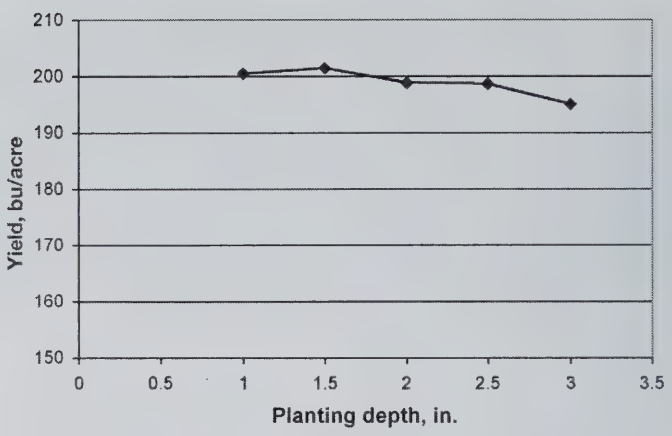


**FIGURE 3 • Planting depth effect on corn yield, averaged over 3 years at Urbana, Illinois.**

plant spacing present in most fields. Modern planters do a very good job of seed distribution and placement, which has led to a reduction in the problem of uneven spacing, though mistakes are still possible. As a general rule, spending money to try to improve a stand that is less than perfect but within an acceptable range probably will not increase profits much, if any.

In many fields, uniformity of emergence and plant size early in the season probably reduce yields more than does nonuniformity of plant spacing. Planting depth is one factor that affects uniformity of emergence. The ideal depth may vary some depending on soil conditions, but, in most cases, planting 1.5 to 1.75 inches deep is likely to provide the best results (Figure 3). Both deeper and shallower planting tend to place seed in less-uniform conditions, which can contribute to unevenness in emergence time or stand loss.

If planting is done under reasonably good conditions, emergence in a field should normally take place over a period of less than 48 hours. We used a corn seed coating that both delayed and prolonged emergence, and found that yield decreased as a result (Table 2). It was not possible to separate the effects of emergence timing and uniformity in this study, but other evidence exists that nonuniform emergence results in plants that are not uniform in size and that this nonuniformity can result in yield loss. Such yield loss probably occurs when late-developing plants undergo more intense competition from adjoining (larger) plants, and therefore lose more yield than the earlier-emerging, larger plants on either side can compensate for.

**TABLE 2 • Effect of seed coating on timing and uniformity of emergence and on grain yield, Urbana, 1999.**

| Seed | Days to 90% emergence | Duration of emergence (days) | Yield (bushels per acre) | Stand (plants per acre) |
|---|---|---|---|---|
| Untreated | 7 | 2 | 208.7 | 33,189 |
| ½ coated | 17 | 17 | 185.7 | 33,686 |
| Coated | 20 | 11 | 176.4 | 32,110 |
| LSD 0.05 | | | 20.1 | NS |

The ability of seed to emerge quickly and uniformly is another factor that could affect emergence and yield. While assertions have been made that certain seed grades or seed lots might have problems with emergence, such problems are rarely seen. Over two years and two locations in Illinois, different seed grades have performed almost equally well (Table 3). Thus, we have little basis for using seed grade as a performance factor. Some planters may distribute certain seed sizes or grades better than others, but it's unlikely that, once in the ground, seed differs in performance according to size.

In summary, seed placement both horizontally and vertically, into a soil environment that provides good seed–soil contact, a good rooting medium, and adequate plant nutrients and water is vitally important in producing top corn yields. There is little to suggest that a large margin for improvement exists in this area, however. Seed companies compete to develop and deliver seed with genetic ability to emerge well under a range of conditions, with good uniformity and protection against soil pathogens and insects. Equipment companies have worked to produce planters better able to place seed at uniform depth and to distribute seed uniformly, and producers take care to ensure that planting takes place under good soil conditions. There is some room for improvement in all of these areas, of course, but plant stand has diminished as a problem in Illinois, even as planting has moved earlier—and thus into soils that are colder on average.

**TABLE 3 • Corn yield from different seed grades. Data are averages over two Illinois locations (DeKalb and Urbana) and two years (2005 and 2006).**

| Seed grade | Yield (bushels per acre) |
|---|---|
| Small flat | 184.7 |
| Medium flat | 185.5 |
| Large flat | 190.1 |
| Small round | 188.7 |
| Medium round | 188.2 |
| Large round | 186.7 |

# Fitting Wheat into Illinois Cropping Systems

*Emerson D. Nafziger*

Over the past 50 years, winter wheat has gone from being a major part of the Illinois cropping landscape to being a "minor" crop in the state, losing out to corn and soybeans, which today occupy some 21 million acres, compared to less than 1 million acres for wheat. Yields of the three crops have shown a considerable amount of variability over recent years (Figure 1), and the coefficient of variability (CV) for wheat yield over the 11 years from 1996 through 2006 is higher (15%) than those for corn (11%) or soybeans (9%). This relatively high yield variability, along with wheat quality and price volatility, accounts for some of the decline in wheat acreage in recent years.

A related factor that has affected wheat acreage and prospects in Illinois is how the crop has fared in the "competition" with corn and soybeans for space in Illinois fields. Over the past 11 years, average yields of these three crops in Illinois have been 149, 44, and 57 for corn, soybeans, and wheat, respectively. The correlations between corn and wheat yields and between corn and soybean yields over this period are higher ($R^2$ of about 0.25 for both) than the correlation between wheat and soybean yields ($R^2 = 0.08$). This difference likely reflects the fact that wheat responds very well to dry weather early in the season (May and June), soybeans respond well to rainfall after midseason, and corn responds favorably to both of these factors.

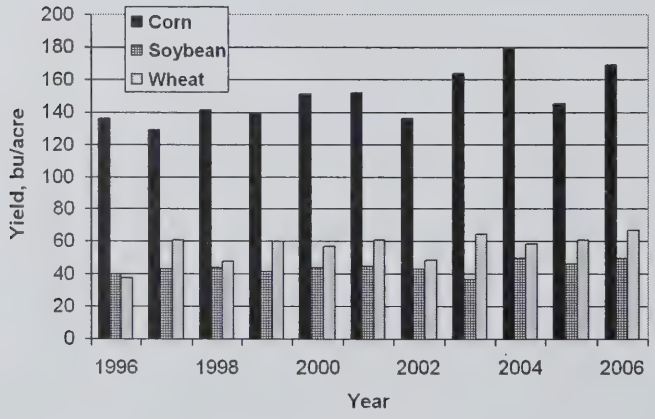


**FIGURE 1 • State average yields of corn, soybeans, and wheat in Illinois, 1996 through 2006 (source: NASS).**

In economic terms, however, with yields averaging less than 40% of corn and only about 30% more than soybeans, and with prices usually not much higher than those for corn, wheat hasn't competed particularly well with corn and soybeans. There are, however, several reasons why we continue to grow wheat in Illinois. One is the chance to doublecrop with soybeans, thus getting two crops from the same field in one year, in the southern half of the state. Doublecropping has little effect on wheat yield, and yields of doublecropped soybeans are variable, but under very good late-summer rainfall, soybeans planted as a doublecrop in June can yield nearly as much as full-season soybeans. In northern Illinois, the short season often makes doublecropping soybeans unfeasible, but wheat yields there tend to be higher due to more favorable weather and more productive soils. Wheat in the northern part of the state tends to be in areas where soils make corn and soybean production riskier, and on livestock farms where wheat provides opportunity to harvest straw, perhaps start a legume crop, and tile or haul manure before fall-harvested crops are harvested.

In the mid-1990s, we started an experiment in western Illinois to measure the performance of wheat in a 3-year rotation and to compare yields and economic returns

in that system to the corn-soybean rotation and to continuous corn and continuous soybeans. The 3-year rotation includes corn, soybeans, and wheat in both possible sequences (C-S-W and S-C-W), and it also includes tilled versus no-till as subplots within the main rotations. All crops in each sequence appear in separate plots each year. The experiments were established at two locations—on a productive silt loam soil at Monmouth, in Warren County, and on a productive creek-bottom soil near Perry, in Pike County.

Corn yields in the 3-year rotation at Monmouth were 6 to 10 bushels higher than in the soybean-corn rotation, and the S-W-C yield was slightly higher than the W-S-C yield (Figure 2). Continuous corn performed poorly, especially under no-till. Soybeans also yielded 4 to 6 bushels more in the 3-year rotation compared to the C-S rotation, and the soybeans in the C-W-S rotation yielded about 3 bushels more than in the W-C-S rotation (Figure 3). Continuous soybeans yielded 6 to 8 bushels less than C-S, and tillage had little effect on soybean yield. Wheat in the C-S-W rotation yielded 5 to 6 bushels more than in the S-C-W rotation and about 3 bushels more when tilled compared to no-till (Figure 4).

Returns in each of the crop sequences were compared using costs given in Table 1. Prices used in this analysis were corn at $2.25 per bushel, soybeans at $5.80 per bushel, and wheat at $3.20 per bushel. There were no adjustments for government payments, nor was the value of wheat straw (or other crop residue) included. The most profitable system under this analysis was the

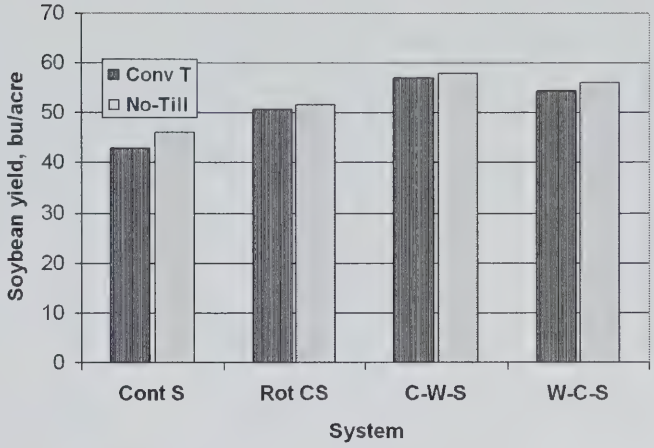


**Figure 3 • Average soybean yields under four crop sequences at two tillage treatments at Monmouth, Illinois. Data are averaged over 6 years, 2000 through 2005.**

3-year sequence W-S-C, followed closely by W-C-S, which performed similarly to the S-C rotation (Figure 5). Continuous soybeans had lower returns than the multiple-crop rotations, especially when tilled. Continuous corn, for reasons that are not clear, was by far the least profitable of all systems. No-till produced more return than tilled soils in all cropping sequences.

At Perry (data not shown), returns for continuous corn were much higher than at Monmouth, but continuous corn still produced the least return of all sequences. At this location, the C-S rotation performed the best, in economic terms, and continuous soybeans produced

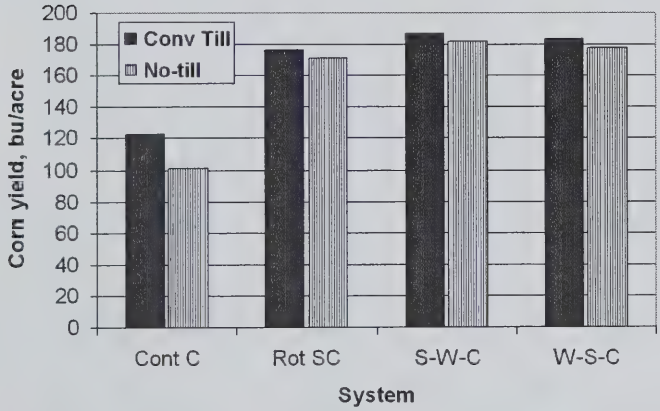


**Figure 2 • Average corn yields under four crop sequences at two tillage treatments at Monmouth, Illinois. Data are averaged over 6 years, 2000 through 2005.**

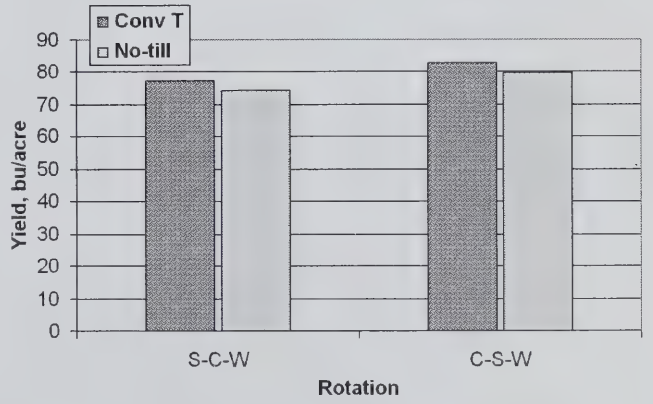


**Figure 4 • Average wheat yields under four crop sequences at two tillage treatments at Monmouth, Illinois. Data are averaged over 6 years, 2000 through 2005.**

**TABLE 1 • Estimated production costs for corn, soybeans, and wheat in the rotation study (source: modified from Illinois Farm Business Farm Management Association records, with some adjustments).**

| Crop | System | Tillage and planting | Fertilizer | Pesticide $ per acre | Seed | Other | Total |
|---|---|---|---|---|---|---|---|
| Continuous corn | Conventional tillage | 28 | 86 | 50 | 40 | 23 | 227 |
| | No-till | 8 | 86 | 50 | 40 | 23 | 207 |
| Rotated corn | Conventional tillage | 23 | 72 | 39 | 40 | 23 | 197 |
| | No-till | 8 | 72 | 39 | 40 | 23 | 182 |
| Soybean | Conventional tillage | 23 | 24 | 28 | 30 | 11 | 116 |
| | No-till | 8 | 24 | 28 | 30 | 11 | 101 |
| Wheat | Conventional tillage | 18 | 49 | 8 | 24 | 9 | 108 |
| | No-till | 8 | 49 | 8 | 24 | 9 | 98 |

returns competitive with those from the 3-year rotations under no-till. The order of crops in the 3-year rotation had little effect on net returns from that system.

These results suggest that including wheat in the rotation has a small, beneficial effect on corn and soybean yields and that the three-crop sequence might hold economic promise.

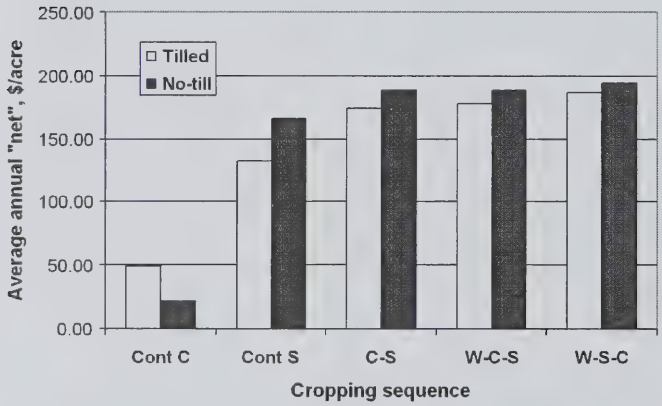


**Figure 5 • Return over direct cropping costs for four crop sequences and two tillage treatments at Monmouth, Illinois. Data are averaged over 6 years, 2000 through 2005.**

So will wheat make a comeback in areas where nearly all fields now grow corn or soybeans every year? All three crops currently enjoy higher prices as a result of high demand and lower worldwide yields, especially of wheat, in recent months. The price signals for wheat are especially strong, for hard wheat more than for the soft wheat that is commonly grown in Illinois. Wheat also is the best of the three crops in providing cover for sloping soils to reduce soil loss during the noncropping season. In terms of economic potential, however, corn, with the proven ability to produce more than 200 bushels per acre in most fields in Illinois, remains the crop of choice for many producers, and is likely to remain so as demand for corn grows. Wheat is, however, perhaps the best choice currently available as a third crop: it has a ready market, it provides some stability within cropping systems, it spreads workloads and costs less to produce than other crops, and it can produce extra income from straw in some venues.

# Wheat Disease Management

*Gregory Shaner*

Several diseases can afflict wheat in the eastern Corn Belt. Among these are rusts, powdery mildew, leaf and glume blotch, and *Fusarium* head blight. Of the three rusts that attack wheat, leaf rust is our greatest threat. Stem rust occasionally infects soft winter wheat, but it develops best in hot weather (68°F to 86°F). With the change to production of early-maturing varieties about 50 years ago, the risk of stem rust diminished because these varieties mature before the disease can become severe. Conversely, cool weather (50°F to 59°F) favors stripe rust. In the Corn Belt, spring weather progresses so quickly from too cold to too hot that stripe rust does not have time to become a problem. Temperature in this region is typically favorable for leaf rust (59°F to 72°F), and this disease occurs to some extent every year. On a susceptible variety, rust spreads rapidly. It may increase from only one or two infections per plant to complete destruction of foliage in less than 30 days.

Powdery mildew is more of a problem in Michigan and Ohio than in Illinois and Indiana, possibly because of cloudier weather in the former two state during the period of vegetative growth in the spring. Nonetheless, the disease can be severe on susceptible varieties throughout the region when weather is conducive.

Two fungi are mainly responsible for leaf blotch in the eastern Corn Belt: *Stagonospora nodorum* and *Septoria tritici*. Leaf blotch is severe when there are frequent rains throughout the spring and early summer. Several periods of more or less continuous light rain for two or three days are more favorable for disease development than more widely spaced, heavy rains. The optimal temperature range for *Septoria* blotch is 59°F to 68°F. If night temperatures remain above 47°F and there is sufficient moisture early in the season (late March through early May), this pathogen will predominate. Symptoms first appear on the oldest leaves, commonly those near the soil surface. Subsequent infections appear progressively higher up the plant and can lead to premature death of all leaves. *Stagonospora* blotch likewise requires frequent, long periods of wetness on foliage, but is favored by higher temperatures (68°F to 80°F). If wet weather persists into May, this disease can progress rapidly. *Septoria* infects only leaves; *Stagonospora* can infect heads as well, to cause glume blotch.

In our region, rusts and leaf blotch rarely become severe until after kernels have formed. Therefore, these diseases do not reduce the number of kernels per head. They interfere with kernel filling, so grain is shriveled and has low test weight. Powdery mildew does much of its damage earlier in the season. One of its main effects is to shut down development of tillers. In a severely infected crop, heads will fail to emerge on most tillers, or, if they do, they produce no grain. Thus, only main culms produce grain, and yield is reduced accordingly.

*Fusarium graminearum* (*Gibberella zeae*) causes head blight. The same fungus causes stalk rot and ear rot of corn and is a common decomposer of corn residue even in fields without pre-harvest stalk rot. The fungus produces tiny fruiting bodies and spores on corn residue. When temperatures remains in the range of 48°F to 86°F and relative humidity is above 90% during much of the time from a week before wheat flowers through late milk, the disease will be severe. The fungus produces spores on corn residue that infect wheat flowers and young kernels. The most vulnerable stage for infection is after anthers have shed pollen but are still attached to the head. The fungus infects these spent anthers, and from there invades the

developing kernel. Once the fungus has infected a single floret, it grows into the rachis and spreads up and down the spike to infect more kernels. Kernels infected early are so shriveled that they are ejected with the chaff during harvest. The harvested grain, however, will have poor test weight and contain chalky kernels (tombstones). In addition to loss of yield and test weight, *Fusarium* produces mycotoxins, principally deoxynivalenol (DON), in grain.

Production of resistant varieties is the chief means of reducing damage from diseases. Varieties highly resistant to rusts and powdery mildew have long been available, although not every variety on the market today is resistant to these diseases. Efforts to breed for resistance to *Septoria* and *Stagonospora* blotches have been under way for 50 years, but progress has been slow and limited. No variety is highly resistant, particularly to *Stagonospora*, but some have moderate resistance. On these varieties, the upper two leaves remain green for 10 to 14 days longer than they do on a susceptible variety, which protects yield and test weight to some degree.

Resistance to head blight has been a major breeding objective for only the past 10 years. A few recently developed varieties have some resistance, and breeders will likely develop varieties with greater resistance in the future. Unfortunately, there is some concern that resistance to head blight does not always mean lower levels of DON in the grain.

Entomologists developed the fly-free planting date concept many years ago to reduce the risk of damage by Hessian fly. It turns out that this planting guideline also reduces risk of damage from powdery mildew, *Septoria* blotch, and yellow dwarf (a viral disease). Powdery mildew develops especially well on wheat that has been provided high rates of nitrogen fertilizer. Rust and leaf blotch may also be favored by high nitrogen rates because the thicker canopy holds moisture on leaves. Planting after the fly-free date and avoiding excessive nitrogen rates reduces the risk of these diseases.

Several foliar fungicides are registered for use on wheat against rusts, powdery mildew, and leaf and glume blotch. Although sprayed fields usually have less disease, an economic return from treatment is not ensured. Time of application, disease pressure, and variety all influence the outcome of treatment. None of the registered products includes head blight on the label. Folicur is moderately effective against this disease and has been available under a Section 18 exemption in several states. This fungicide is applied at the onset of flowering.

# Development of Fusarium Head Blight–Resistant Wheat Varieties

*Frederic L. Kolb*

Scab, or Fusarium head blight (FHB), causes significantly lower grain yield, lower test weight, reduced grain quality, and reduced milling yield, and the fungus produces trichothecene mycotoxins (such as deoxynivalenol, or DON) that are detrimental to both humans and livestock. The best way to minimize economic losses due to scab is through integrated pest management combining a number of control strategies including use of scab-resistant varieties, production of several varieties that differ in maturity, and application of a fungicide when necessary. An important component in controlling scab is the production of resistant varieties. Thus, introduction of scab-resistant wheat varieties contributes to improved food safety and reduces losses suffered by producers.

Different types of host plant resistance to scab have been described. including (1) resistance to initial infection, (2) resistance to invasion of plant tissue by the fungal hyphae, (3) development of well-filled kernels in infected plants, (4) inhibition of translocation or degradation of deoxynivalenol or resistance to accumulation of mycotoxins, and (5) yield tolerance (Stack 2000). Resistance to scab is quantitative, and different mechanisms of resistance are controlled by different genes (Bai and Shaner 1994, 2004). Development of varieties with a high level of scab resistance may require combining scab resistance from several sources (Singh and van Ginkel 1997). In the University of Illinois breeding program, we have emphasized this strategy of combining several "types" of scab resistance. We have placed much emphasis on evaluation of the percentage of Fusarium-damaged kernels (FDK), and we developed the incidence/severity/kernel rating (ISK) index (Kolb and Boze 2003) as a means to better evaluate experimental lines that combine several "types" of resistance. Verges et al. (2006) confirmed that scab resistance needs to be evaluated over several years and environments.

In years when environmental conditions favor infection, scab has resulted in huge economic losses to wheat producers; therefore, there is an immense need to develop wheat varieties with high levels of resistance to this disease. The long-term objective in my wheat breeding project is the development of soft red winter wheat genotypes with excellent scab resistance combined with high yield potential, winter hardiness, acceptable milling and baking quality, and resistance to other diseases. The short-term objectives are to (1) combine genes for scab resistance from diverse sources, (2) evaluate the breeding lines produced from crosses involving several sources of scab resistance, (3) identify breeding lines with better scab resistance than any of the parents, and (4) provide data on scab resistance of current varieties to producers.

Specific crosses have been made to combine genes for scab resistance from different sources into genotypes that can be used in breeding programs developing scab-resistant varieties. Some populations include several soft red winter wheat lines with moderate resistance, or populations developed from crosses involving two or more diverse sources of scab resistance. Producers are attracted to the highest yielding varieties. If these varieties are also scab susceptible, when the environment favors scab infection, severe losses occur. Therefore, combining scab resistance with high yield potential and other traits required in a successful, adapted variety is extremely important.

Wheat is most susceptible to infection to scab during and just after flowering. Under natural environmental conditions, scab evaluations are often confounded with time of flowering. To ensure that scab can be evaluated every year, we use a scab evaluation field nursery where the plots can be misted daily for several weeks when the wheat is flowering. The nursery is inoculated using grain spawn scattered in the nursery. A mixture of isolates is used in the culture of the inoculum. In addition, corn stalks are scattered in the nursery in the fall following wheat seedling emergence, and a spore suspension of a mixture of isolates is sprayed on the corn stalks.

Experimental breeding lines for evaluation are planted in rows 3 feet in length, and an irrigation system provides daily misting during flowering (three 45-minute to 1-hour periods in a 24-hour period). Rows of plants in the field are evaluated based on incidence and severity using a rating scale. Data are collected on incidence and severity, and the FHB index is calculated. Incidence is based on assessing the percentage of heads in a row that show symptoms. Severity is based on assessing the percentage of scabby spikelets in seven to ten heads per row. Visual estimates of infected spikelets may not give an accurate assessment of kernel damage; therefore, prevalence of shriveled kernels (FDK, Fusarium-damaged kernels) is determined. The percentage of Fusarium-damaged kernels (% FDK) is determined for each sample. The ISK index is computed using the formula: 0.3 (% incidence) + 0.3 (% severity) + 0.4 (% FDK). The ISK index varies from 0 to 100. Samples from the breeding lines evaluated are sent to Michigan State University for DON analysis. The use of the ISK index and DON level for selection is very important to ensure that breeding lines will be acceptable to the milling and baking industry.

The development of scab resistant varieties includes the following steps:

1. Make crosses to create genetic variability. Our emphasis is on combining scab resistance with high yield and other traits required for successful, adapted varieties.
2. Advance the populations for several generations.
3. Select for scab resistance in segregating generations, and identify individuals with the highest level of resistance. Thousands of heads are selected from populations with scab-resistant parents crossed to parents with high yield combined with excellent plant type and other desirable agronomic traits. These lines are then evaluated for scab resistance in the field.
4. Evaluate experimental lines and currently grown varieties for scab resistance, and select lines using both the greenhouse inoculation methods and the field evaluation nursery.
5. Evaluate scab-resistant lines for yield, agronomic traits, and resistance to other diseases. Scab resistance is only one trait required in an adapted variety; therefore, experimental breeding lines with scab resistance are also evaluated for many other characteristics.
6. Release breeding lines for commercial production. When breeding lines with potential for commercial production are developed, they are released to the seed industry. Development of a variety from the time a cross is made until a variety is released can take 10 to 12 years. In 2006, four wheat breeding lines were released for brand labeling. Several of these lines were produced in large increases in 2006 and should be in seedsmen's fields in the fall of 2006 or 2007.

Data are collected on the scab resistance of some current varieties, and the information about the scab resistance of numerous current varieties is available at the Illinois Variety Testing Web site at http://vt.cropsci.uiuc.edu/wheat.html. At the site, click on "Fusarium Head Scab Ratings of Varieties."

Table 1 summarizes data from several years for varieties evaluated in the scab field nursery. This information can be used to aid in variety selection and to avoid planting varieties that are very susceptible to scab. This is crucial to the reduction of risk due to damage from scab infection.

## References


Bai, G., and G. Shaner. 1994. Scab of wheat: Prospects for control. *Plant Disease* 78:760–766.

Bai, G., and G. Shaner. 2004. Management and resistance in wheat and barley to Fusarium head blight. *Annual Review of Phytopathology* 42:135–161.

Kolb, F.L., and L.K. Boze. 2003. An alternative to the FHB index: Incidence, severity, kernel rating (ISK) index (abstract). In Proceedings of the 2003 National Fusarium Head Blight Forum, Minneapolis, MN, December 13–15, 2003. U.S. Wheat and Barley Scab Initiative, Michigan State University, East Lansing, MI.

**TABLE 1 • 2005–2006 Fusarium head scab evaluation of selected entries from the University of Illinois variety trial. Sorted by 2006 ISK index, lowest (most resistant) to highest (most susceptible). Varieties with greater resistance have lower numbers.**

| | | 2006 | | | | | 2005 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Company | Entry name | Incidence (%)[1] | Severity (%) | Kernel rating (% FDK)[2] | FHB index (0–100) | ISK index (0–100) | Incidence (%)[1] | Severity (%) | Kernel rating (% FDK)[2] | FHB index (0–100) | ISK index (0–100) | DON |
| Pioneer Hi-Bred Int'l | 25R51 | 26.7 | 16.6 | 30 | 4.4 | 25.0 | — | — | — | — | — | — |
| Public | Ernie | 33.3 | 44.7 | 7 | 14.9 | 26.1 | 43.3 | 52.1 | 37 | 19.7 | 43.3 | 2.6 |
| AgriPro COKER | Coker 9511 | 60.0 | 11.0 | 22 | 6.2 | 30.0 | — | — | — | — | — | — |
| Excel Brand Seeds | Excel 361 | 55.0 | 34.8 | 13 | 23.8 | 32.3 | — | — | — | — | — | — |
| Excel Brand Seeds | Excel 307 | 40.0 | 47.6 | 27 | 21.3 | 36.9 | 24.3 | 46.3 | 40 | 10.6 | 37.2 | 2.5 |
| Excel Brand Seeds | Excel 173 | 41.7 | 40.6 | 33 | 20.9 | 38.0 | — | — | — | — | — | — |
| Excel Brand Seeds | Excel 442 | 33.3 | 60.2 | 27 | 20.6 | 38.7 | — | — | — | — | — | — |
| Excel Brand Seeds | Excel 400-1 | 35.0 | 55.2 | 30 | 19.7 | 39.1 | 30.0 | 63.6 | 40 | 19.5 | 44.1 | 2.7 |
| Pioneer Hi-Bred Int'l | 25R54 | 56.7 | 42.4 | 27 | 27.1 | 40.4 | 80.0 | 51.6 | 47 | 43.4 | 58.2 | 7.1 |
| Public | Truman | 53.3 | 62.8 | 15 | 34.6 | 40.9 | 23.3 | 14.7 | 47 | 3.4 | 30.1 | 5.1 |
| GROWMARK | FS 634 | 41.7 | 62.3 | 25 | 26.9 | 41.2 | 25.0 | 52.3 | 30 | 16.0 | 35.2 | 2.4 |
| Excel Brand Seeds | Excel 211 | 50.0 | 55.2 | 27 | 27.1 | 42.2 | 10.0 | 42.5 | 20 | 3.0 | 23.7 | 3.3 |
| GROWMARK | FS 645 | 60.0 | 40.6 | 30 | 24.1 | 42.2 | — | — | — | — | — | — |
| Excel Brand Seeds | Excel 399 | 51.7 | 65.3 | 20 | 34.1 | 43.1 | 48.3 | 56.3 | 33 | 28.0 | 44.8 | 3.1 |
| GROWMARK | FS 8309 | 53.3 | 42.1 | 37 | 23.1 | 43.3 | 31.7 | 38.2 | 43 | 11.4 | 38.3 | 4.9 |
| Public | Roane | 66.7 | 47.8 | 27 | 34.6 | 45.0 | 63.3 | 32.6 | 30 | 20.4 | 40.8 | 3.2 |
| Excel Brand Seeds | Excel 176 | 60.0 | 66.9 | 25 | 40.1 | 48.1 | — | — | — | — | — | — |
| JGL | JGL 603 | 56.7 | 56.5 | 37 | 31.7 | 48.6 | — | — | — | — | — | — |
| Public | Kaskaskia | 61.7 | 60.1 | 38 | 38.2 | 51.8 | 86.7 | 57.5 | 43 | 50.0 | 60.6 | 4.5 |
| Excel Brand Seeds | Excel 410 tw | 60.0 | 56.7 | 43 | 33.9 | 52.3 | 38.3 | 62.6 | 33 | 21.1 | 43.6 | 3.2 |
| Public | McCormick | 71.7 | 59.3 | 37 | 43.1 | 54.0 | 95.0 | 40.5 | 37 | 38.4 | 55.3 | 5.0 |
| Ohio Seed Imp. Assn. | Bravo | 73.3 | 58.8 | 37 | 43.6 | 54.3 | 75.0 | 64.9 | 33 | 47.7 | 55.3 | 3.5 |
| Pioneer Hi-Bred Int'l | 25R63 | 56.7 | 63.2 | 47 | 37.3 | 54.7 | — | — | — | — | — | — |
| GROWMARK | FS 8302 | 61.7 | 60.5 | 50 | 37.9 | 56.7 | 76.7 | 57.9 | 63 | 42.6 | 65.7 | 5.8 |
| Pioneer Hi-Bred Int'l | 25R37 | 76.7 | 42.4 | 53 | 32.8 | 57.1 | 90.0 | 31.1 | 53 | 27.0 | 57.7 | 4.5 |
| Pioneer Hi-Bred Int'l | 25R47 | 75.0 | 63.7 | 43 | 47.3 | 58.9 | 91.7 | 47.4 | 53 | 44.2 | 63.0 | 23.0 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AgriPro COKER | Coker 9436 | 70.0 | 55.7 | 53 | 37.2 | 59.0 | 95.0 | 54.1 | 53 | 51.8 | 66.1 | 7.4 |
| AgriPro COKER | Coker 9312 | 85.0 | 54.7 | 43 | 46.2 | 59.3 | 73.3 | 50.2 | 40 | 37.5 | 53.1 | 5.0 |
| Public | Patterson | 73.3 | 82.0 | 33 | 58.4 | 59.9 | 58.3 | 66.4 | 33 | 40.2 | 50.8 | 3.8 |
| AgriPro COKER | Cooper | 65.0 | 66.0 | 53 | 42.7 | 60.7 | 93.3 | 54.7 | 60 | 51.0 | 68.4 | 5.9 |
| AgriPro COKER | Branson | 70.0 | 78.6 | 43 | 54.8 | 61.9 | — | — | — | — | — | — |
| Pioneer Hi-Bred Int'l | 25R78 | 70.0 | 80.7 | 47 | 56.5 | 63.9 | 93.3 | 65.3 | 33 | 60.2 | 60.9 | 6.2 |
| Public | Cardinal | 70.0 | 72.5 | 53 | 50.3 | 64.1 | 38.3 | 44.9 | 53 | 18.0 | 46.3 | 4.8 |
| Public | Sisson | 96.7 | 54.8 | 57 | 53.5 | 68.1 | 88.3 | 49.7 | 63 | 43.6 | 66.7 | 13.5 |
| AgriPro COKER | Coker 9553 | 73.3 | 76.2 | 60 | 55.7 | 68.9 | — | — | — | — | — | — |
| Excel Brand Seeds | Excel 392 | 81.7 | 75.6 | 60 | 61.4 | 71.2 | 68.3 | 61.9 | 47 | 42.1 | 57.7 | 5.9 |
| Public | Madison | 76.7 | 73.0 | 70 | 56.3 | 72.9 | 96.7 | 67.1 | 60 | 64.8 | 73.1 | 4.2 |
| GROWMARK | FS 657 | 78.3 | 85.3 | 60 | 66.6 | 73.1 | — | — | — | — | — | — |
| AgriPro COKER | Benton | 81.7 | 69.4 | 70 | 57.0 | 73.3 | 65.0 | 51.6 | 53 | 37.1 | 56.3 | 5.2 |
| GROWMARK | FS 637 | 93.3 | 74.6 | 67 | 69.3 | 77.0 | — | — | — | — | — | — |
| | Test Average | 60.1 | 56.3 | 37.9 | 35.7 | 50.1 | 58.7 | 54.1 | 42.5 | 33.1 | 50.8 | |
| | LSD (0.05) | 26.3 | 21.5 | 19.2 | 19.6 | 14.6 | 31.6 | 22.4 | 23.7 | 21.4 | 16.8 | |

[1]Incidence = the percentage of heads in a row with symptoms.

[2]Kernel rating = the percentage of shriveled seed.

Singh, R.P., and M. van Ginkel. 1997. Breeding strategies for introgressing diverse scab resistance into adapted wheats, pp. 86–92. In Dubin, H.J., L. Gilchrist, J. Reeves, and A. McNab (eds). *Fusarium Head Scab: Status and Future Prospects*. CIMMYT, Mexico, DF.

Stack, R.W. 2000. *Return of an Old Problem: Fusarium Head Blight of Small Grains. Plant Health Progress* (http://www.plantmanagementnetwork.org/php/default.asp).

Verges, V.L., D. Van Sanford, and G. Brown-Guedira. 2006. Heritability estimates and response to selection for Fusarium head blight resistance in soft red winter wheat. *Crop Science* 46:1587–1594.

# Managing Insects in Wheat: An Overview

*Douglas W. Johnson*

Kentucky is located in a unique ecological situation between the cold winters of the northern Prairie states and the very mild winters of the Deep South. Though cold enough to stop most insect activity during midwinter, the great variation in date of first frost, fall onset of continuous cold, and spring onset of general warm weather makes it particularly difficult to predict insect impact in any given year.

In Kentucky, wheat is grown as a winter crop planted in the fall, usually following corn, and harvested the following summer. Most often, varieties that mature early enough to allow planting of double-crop soybeans are used (Sandell 2002). This production system divides the insect pests into three groups: those that infest in the fall and that either do or do not overwinter, and those that infest in the spring. We will examine these pests in order of appearance through the production year.

Insect pests are common in Kentucky wheat. Typically, one can find all of these insects in almost every field every year, but rarely do their populations grow to economically important numbers. Nonetheless, each pest has the potential to cause significant damage under appropriate conditions.

What will this information mean to Illinois farmers? Generally, the situation in southern Illinois is very similar to that in western Kentucky. Conversely, as one moves farther north, the likelihood of encountering these pests, especially in economically important situations, is very much reduced. In any given year, the importance of several of these pests, particularly Hessian fly and the cereal aphid–barley yellows virus complex, depends on the short-term weather—most importantly, temperatures.

## Scouting

In general, Kentucky-grown grain should be scouted weekly to determine pest activity and plant growth stage from plant emergence to maturity when the temperature is above 48°F, which provides the best description of pest status and plant stage and allows important management decision to be made in a timely manner. An outline for taking this data in a standard format can be found in the University of Kentucky Integrated Pest Management (UK-IPM) scout manual for small grains (Lucas 2006). In addition, there are other methods of collecting data on important pests, such as the use of pheromone-baited traps to capture adult moths (Johnson 1994c). Whatever method you choose, use randomly assigned data collection points to avoid "selecting" your data (Johnson 1994b).

## Insect Pests in General Order of Appearance

Note: In this paper, common and scientific names of insects are from *Common Names of Insects and Related Organisms*, an online database published by the Entomological Society of America (http://www.entsoc.org/pubs/common_names).

### *Fall Pests*

The **fall armyworm**, *Spodoptera frugiperda* (J.E. Smith), is a common pest of several late summer- and early fall-planted crops. Fall armyworm (FAW) cannot overwinter in Kentucky. FAW migrates into Kentucky from the Gulf Coast in midsummer, initially infesting corn and grain sorghum as its primary crop hosts. In late summer/early fall, as corn and sorghum begin to mature, FAW colonizes

newly seeded grasses. Damage is most common in lawns, reclaimed land, ditch banks, roadsides, and similar areas, but FAW may also infest small grains. FAW can result in seedling death if it feeds on new plants before roots are established. If plants are established, FAW feeding is more like grazing. FAW can remain active until the first killing frost and will survive longer where crop residue provides shelter from the cold (as with conservation tillage).

Infestation typically results from early planting. Often, planting after the Hessian fly–free date will avoid infestation. Occasionally, frost and the onset of cold weather are late enough to allow infestation of small grains, even after the fly-free date. Insecticidal control is relatively easy, but there are no established thresholds. Damaged fields are sometimes replanted, but this is a risky technique. Many damaged plants will survive; thus, replanting may result in a denser than desirable stand. Very dense stands will, in turn, result in problems in the spring such as lodging and increased armyworm and disease pressure.

### *Fall and Spring Pests*

The cereal aphid complex comprises four common grain aphids: bird cherry-oat aphid, *Rhopalosiphum padi* (Linnaeus); corn leaf aphid, *Rhopalosiphum maidis* (Fitch); greenbug, *Schizaphis graminum* (Rondani); and English grain aphid, *Sitobion avenae* (Fabricius), which are considered the most important aphid pests in our region. In addition, the rice root aphid, *Rhopalosiphum rufiabdominalis* (Sasaki), very likely plays an important role, though little is known about this aphid in Kentucky. It is interesting to note that these aphids are not considered important for their direct damage. Though some information on the importance of direct damage, particularly from the bird cherry-oat aphid, is coming to light, they are by far more notorious for their ability to spread the viral pathogens that result in barley yellow dwarf (BYD) disease. On the other hand, there are at least 25 aphids that can move the yellows viruses among plants. Regardless of the aphids present, the risk—real and perceived—of barley yellow dwarf, and, by association, the cereal aphid complex, is undoubtedly the major driver of insecticide use in Kentucky-grown wheat (Johnson and Townsend 1999).

Though other insects may require insecticidal control from time to time, only the cereal aphids are routinely treated. Beginning in the early 1990s, increases in insecticide use, especially the systemic disulfoton (Di-Syston), and, in the mid-1990s, the synthetic pyrethroid lambda-cyhalothrin (primarily Karate and Warrior) over the historic use pattern were quite evident (Johnson and Townsend 1999). Moreover, there has been some historic use of systemic insecticide seed treatments, primarily imidacloprid (Gaucho) and now thiamethoxam (Cruiser). Use of these latter seed treatment products is likely to increase.

Control of the cereal aphid complex is relatively easy to obtain. As with most other insect pests of wheat, it is hard to decide whether treatment is warranted. The difficulty of finding aphids, combined with the small number required for application, the relative low cost of insecticides, and the fear of catastrophic loss to BYD, probably results in more insecticide use than is needed to mitigate the risk. The treatment of these questions is dealt with in the southeastern region in a new publication due out soon (Flanders et al., in press).

The **Hessian fly**, *Mayetiola destructor* (Say), is another common insect pest infesting small grains in the fall (Johnson 1993b). In general, planting after the "fly free" date will provide adequate control in Kentucky. Agronomic and cultural factors favoring strong stems and stand-ability of the plant are preferred, but, at last examination, all resistance factors can be overcome by the biotypes present in the state. There are no rescue treatments (foliar-applied insecticides), though use of systemic insecticides as seed treatments and fall or spring foliar applications of systemic insecticides have been used in the Deep South to combat this problem. Here, in the presence of good agronomic practices, preapplied insecticide treatment is not warranted.

The **wheat curl mite**, *Aceria tosichella* Keifer, is a common pest of wheat in Nebraska and other Plains states but is rarely a problem in the Midwest. Wheat curl mite (WCM) was first noticed in Kentucky in 1987, with a larger outbreak in 1988 (Townsend et al. 1996). Since that time, a significant infestation of WCM mite occurred in south central Kentucky in 2000, with smaller, scattered infestations in more recent years.

It was first believed that outbreaks of this pest were the result of mites carried in on winds from more western production areas. Though this is possible, and wind is a method of dispersal, it appears more likely that this outbreak occurred because of the lack of weed control (thus, an increase in volunteer wheat) in soybeans during the preceding summer. Volunteer wheat provides a "green bridge" that may have allowed WCM to "oversummer" and build into much larger than normal numbers. This is the usual cause of economic problems with WCM in

the Western states. Typically, there would be no green bridge in Kentucky. Conversely, in some poor soybean production years, weed control is reduced or abandoned; thus, volunteer wheat remains in fields.

## Spring Pests

The **cereal leaf beetle**, *Oulema melanopus* (Linnaeus), was first noted feeding in south central Kentucky in the mid-1980s (Johnson 1993a). Since that time, it has moved generally westward to the Mississippi River counties. Cereal leaf beetle (CLB) is a sporadic pest with a tendency to damage the later-maturing varieties.

Control of CLB is comparatively easy. Still, determining the need to control in a timely fashion is the more important decision. Work done in the late 1990s (Herbert and Van Duyn 1999) produced scouting procedures and thresholds that are currently in use. However, this insect is so rarely a problem that it is likely the "old" threshold of one CLB per head-bearing stem is most often used, except in the most highly managed wheat.

The **armyworm**, *Pseudaletia unipuncta* (Haworth), also known as the "true armyworm," is usually the first pest of wheat to appear in the spring (Johnson 1994a). Armyworm (AW) makes its annual appearance each spring in "flights" of the adult moths. These flights can be monitored by capturing males, using pheromone-baited traps (Johnson and McNeill 1993; Johnson 1994c). The numbers caught using this technique can provide advance warning of the insect, allow calculation of when the damaging stage (worm) will appear (Johnson et al. 1998), and can be compared to trap capture data from previous years (Lucas, Insect Trap Data, various dates).

AW is very common in Kentucky but only rarely does damage sufficient to warrant control. In spite of this, spectacular outbreaks of this pest do occur. One recent outbreak occurred in 2001. In that year, our early peak trap captures were more than three times the average (Lucas, Insect Trap Data and IMP Trap Counts, various dates). Very large populations appeared first in the South, then progressively through the Midwest into Canada. Considerable damage was done to the first cutting of grass hay in Kentucky. Conversely, effects on small grains are debatable because of the late occurrence of the infestation.

AW is most often controlled by naturally occurring predators and parasitoids. For example, eggs of tachinid flies (Diptera: Tachinidae) are commonly found just behind the head on armyworm larvae. Very dense plant stands, especially with lodging and cool, cloudy springs, favor AW populations. Insecticidal control is relatively easy, if necessary.

## Important Natural Enemies

There are many natural control agents operating in the small grain fields of Kentucky. As previously mentioned, caterpillars parasitized by tachinid flies, plus braconid wasps (Hymenoptera: Braconidae) and infections by fungal and viral pathogens are often seen. Braconid parasitoids in the genus *Aphidius* have been collected from the grain aphids. In addition, a plethora of predators, such as ground beetles, (Coleptera: Carabidae) and syrphid flies (Diptera: Syrphidae), are easily observed. Though often given short shrift, these natural controls, combined with good cultural practices, probably account for much of the insect pest control in Kentucky wheat.

## Pesticide Strategies

Insecticide use is an important tool in managing insect pests in small grains (Johnson, Insecticide Recommendations, updated annually). Still, *whether*, *when*, and *how* applications are made are often more important than *which* insecticide is used. This is especially true when calculating economic returns.

### *Soil-Applied Insecticides*

The decision to use soil-applied insecticides must be made before planting. Treatments are very general, are broadcast over a wide area, and affect many animals other than the target pests. Few insecticides are available, and most are relatively toxic.

### *Seed-Applied, Systemic Insecticides*

Like soil insecticides, seed-applied insecticides must be chosen before planting—in fact, when the seed is purchased. Treatments are more targeted and primarily affect insects that feed directly on the plant. They are a good choice for crops at increased risk to BYD (early planted) but are relatively more expensive than other applications.

### *Foliar-Applied Insecticides*

The decision to use foliar-applied insecticides can be made as pests begin to appear. Like the soil insecticides, foliar applications are general applications made over a broad area and affect many animals other than the target

pests. If, however, they are targeted in time and area and based on pest threshold values, they are probably the most cost effective. They require the most management skill to be used correctly.

## References

You may find the references listed below to be of some use. Nonetheless, you should recognize that entomologist and crop production specialists in your state(s) will have similar publications tailored for your production area(s).


Entomological Society of America. No date. *Common Names of Insects and Related Organisms* (http://www.entsoc.org/pubs/common_names).

Flanders, K., A. Herbert, D. Buntin, D. Johnson, K. Bowen, J. Murphy, J. Chapin, and A. Hagan. In press. *Barley Yellow Dwarf in Small Grains in the Southeast*. Auburn University, Auburn, AL.

Herbert, Jr., D.A., and J.W. Van Duyn. 1999. *Cereal Leaf Beetle Biology and Management*. Virginia Polytechnic Institute and State University, Publication No. 444-350 (http://www.ext.vt.edu/pubs/entomology/444-350/444-350.html).

Johnson, D. 1993a. *Cereal Leaf Beetle in Kentucky Wheat*. University of Kentucky Entomology Fact Sheet No. 107 (http://www.uky.edu/Ag/Entomology/entfacts/fldcrops/ef107.htm).

Johnson, D. 1993b. *Hessian Fly in Kentucky*. University of Kentucky Entomology Fact Sheet No. 101 (http://www.uky.edu/Ag/Entomology/entfacts/fldcrops/ef101.htm).

Johnson, D. 1994a. *Armyworms in Small Grains*. University of Kentucky Entomology Fact Sheet No. 111 (http://www.uky.edu/Ag/Entomology/entfacts/fldcrops/ef111.htm).

Johnson, D. 1994b. *Procedures for Selecting Random Locations for Sampling*. University of Kentucky Entomology Fact Sheet No. 118 (http://www.uky.edu/Ag/Entomology/entfacts/fldcrops/ef118.htm).

Johnson, D. 1994c. *Using Pheromone Traps in Field Crops*. University of Kentucky Entomology Fact Sheet No. 112 (http://www.uky.edu/Ag/Entomology/entfacts/fldcrops/ef112.htm).

Johnson, D. Updated annually. *Insecticide Recommendations for Small Grains*. University of Kentucky Cooperative Extension Service Publication No. ENT-47 (http://www.uky.edu/Ag/PAT/recs/crop/pdf/Entfact-47.pdf).

Johnson, D., and S. McNeill. 1993. *Plans and Parts List for the "Texas" Style Cone Trap for Monitoring Certain Insect Pests*. University of Kentucky Entomology Fact Sheet No. 010 (http://www.uky.edu/Ag/Entomology/entfacts/fldcrops/ef010.htm).

Johnson, D., and L. Townsend. 1999. *Aphids and Barley Yellow Dwarf (BYD) in Kentucky-Grown Wheat*. University of Kentucky Entomology Fact Sheet No. 121. (http://www.uky.edu/Ag/Entomology/entfacts/fldcrops/ef121.htm).

Johnson, D., R. Bessin, and L. Townsend. 1998. *Predicting Insect Development Using Degree Days*. University of Kentucky Entomology Fact Sheet No. 123 (http://www.uky.edu/Ag/Entomology/entfacts/fldcrops/ef123.htm).

Lucas, P. (ed). 2006. *Kentucky Integrated Crop Manual for Field Crops: Small Grains*. University of Kentucky Integrated Pest Management Publication No. IPM-4. (http://www.uky.edu/Ag/IPM/manuals/ipm4smgr.pdf).

Lucas, P. Various dates. *Insect Trap Data* (archive). University of Kentucky Integrated Pest Management (http://www.uky.edu/Ag/IPM/trapdata/trapdata.htm).

Lucas, P. Various dates. *IPM Trap Counts* (weekly). University of Kentucky Integrated Pest Management (http://www.uky.edu/Ag/kpn/kpn_06/pn060925.htm#trap).

Sandell, L. (ed). 2002. *Crop Profile for Winter Wheat in Kentucky*. NSF Center for Integrated Pest Management (http://pestdata.ncsu.edu/cropprofiles/docs/KYwheat.html).

Townsend, L., D. Johnson, and D. Hershman. 1996. *Wheat Streak Mosaic Virus and the Wheat Curl Mite*. University of Kentucky Entomology Fact Sheet No. 117 (http://www.uky.edu/Ag/Entomology/entfacts/fldcrops/ef117.htm).


## Additional References


*Entomology Fact Sheets*. Published by University of Kentucky Entomology (http://www.uky.edu/Ag/Entomology/entfacts/eflists.htm).

*Kentucky Pest News* (newsletter). Published weekly during field crop season, biweekly in winter. (http://www.uky.edu/Ag/kpn/kpnhome.htm).

# Glyphosate-Resistant Palmer Amaranth Impacts Southeastern Agriculture

*A. Stanley Culpepper and Alan C. York*

Palmer amaranth is among the three most troublesome weeds in Georgia cotton, peanuts, and soybeans and is among the top five most troublesome weeds in most other southeastern states (Webster 2005). It is currently the most prevalent *Amaranthus* species in Georgia agronomic crops, which is likely in response to its competitiveness and aggressive growth habit and prolific seed production. Compared with common waterhemp, redroot pigweed, and tumble pigweed, Palmer amaranth had the greatest values for plant volume, dry weight, and leaf area (Horak and Loughin 2000). Additionally, the rate of height increase per growing degree day for Palmer amaranth was 24% to 62% greater than for the other *Amaranthus* species.

A rapid growth rate and tall stature make Palmer amaranth extremely competitive with crops. Palmer amaranth reduced corn yields 11% to 91%, with 0.5 to 8 plants in 3.3 feet of row (Massinga et al. 2001; Massinga and Currie 2002) and reduced soybean yield 17% to 68%, with 0.33 to 10 plants in 3.3 feet of row (Klingaman and Oliver 1994). Cotton lint yields in Texas decreased linearly from 13% to 54% as Palmer amaranth density increased from 1 to 10 plants in 30 feet of row (Morgan et al. 2001).

Since commercialization of Roundup Ready technology, some southeastern growers have used this technology in a monoculture system and have relied exclusively on glyphosate (Roundup and others) applied multiple times each season to manage Palmer amaranth and other weeds. From commercialization until 2004, these glyphosate programs in Roundup Ready technology effectively and economically controlled Palmer amaranth. Unfortunately, a cotton grower in Macon County, Georgia, was unable to control Palmer amaranth with glyphosate in 2004.

## Confirming Palmer Amaranth Resistance to Glyphosate

### *Field*

The experiment was conducted in two fields in Macon County in 2005. Treatments included the potassium salt of glyphosate at 0, 1.0, 2.25, 4.5, 6.7, and 9.0 lb a.i./A applied at 15 GPA. Palmer amaranth heights and densities at time of treatment ranged from 2 to 4 inches and 10 plants per square foot, respectively, at one location and 3 to 5 inches and 40 plants per square foot at the second location. Glyphosate at 1.0, 2.25, 4.5, 6.7, and 9.0 lb/A controlled emerged Palmer amaranth 8%, 17%, 46%, 70%, and 82%, respectively, 28 days after application. In our experiment, glyphosate at 12 times the recommended rate, or 9.0 lb/A, failed to provide commercially acceptable control.

### *Greenhouse*

Mature Palmer amaranth seeds from the suspect Macon County field site were collected after being treated and surviving three glyphosate (0.75 lb/A) applications. The seedlings (F1 generation) were treated with glyphosate at 1.0 lb/A in the greenhouse and control was only 54%. Plants surviving this 1.0 lb/A application of glyphosate were grown to maturity and crossed. Mature seed (F2 generation) were harvested and then screened to determine the level of resistance relative to a known sensitive biotype.

Seedlings 3 to 5 inches tall were treated with 12 rates of a potassium salt of glyphosate. The level of glyphosate needed to control the Macon County population was eight times that of the known susceptible biotype. This experiment, in conjunction with the field experiment, confirmed that the Palmer amaranth infesting the farm in Macon County, Georgia, is indeed resistant to glyphosate.

At this time, research is under way to confirm suspected resistant biotypes of Palmer amaranth in North Carolina and South Carolina. Suspected resistant populations have been observed in a number of locations in both states. Additionally, glyphosate resistance is suspected, but yet confirmed, in common ragweed in North Carolina and common cocklebur in South Carolina.

## Future Impact on Southeastern Row Crop Agriculture

This is the world's first confirmed case of glyphosate resistance in an *Amaranthus* species (Heap 2005; HRAC 2005), and it is a significant finding with serious ramifications for future weed management. Palmer amaranth is already one of the most troublesome weeds of agronomic crops across the southern United States (Webster 2005); resistance to glyphosate will only exacerbate the problem, especially in light of the widespread planting of glyphosate-resistant crops. Rapid spread by pollen is expected in this dioecious species (forced outcrossing). Moreover, resistance to other herbicides, such as dinitroanilines and acetolactate synthase inhibitors (Heap 2005), limits the options to control glyphosate-resistant Palmer amaranth.

Other *Amaranthus* species are prevalent in all regions of North America, especially in the midwestern and southern areas of the United States, where glyphosate-resistant crops have been broadly adopted. *Amaranthus* species, including Palmer amaranth, can outcross with other related monoecious and dioecious species (Franssen et al. 2001; Tranel et al. 2002; Trucco et al. 2005). Glyphosate resistance in this particular Palmer amaranth population will likely spread to other adjacent *Amaranthus* species by outcrossing, limited only by movement of viable pollen in the atmosphere.

## Initial Results from Glyphosate-Resistant Palmer Amaranth Research

Although research has been conducted for only two years, there are several conclusions that can be drawn from our efforts. Control in cotton will be much more challenging than control in soybeans or corn. In corn, growers have several effective options including programs using atrazine plus a chloroacetamide (Dual, Outlook, etc.) herbicides followed by 2,4-D or dicamba if needed. In soybeans, flumioxazin (Valor) and the chloroacetamides applied at planting have also been effective if activated by rainfall or irrigation. Postemergence control in soybeans is often more challenging than soil-applied options, but several diphenylethers (Blazer, Reflex, etc.) are available for use and can be effective if growers are timely with applications. However, cotton production will likely be more costly and challenging for growers. More than 95% of the cotton acreage in the Southeast is Roundup Ready because glyphosate effectively controls Palmer amaranth. Once Palmer populations become resistant to glyphosate, the only other postemergence over-the-top herbicide options in conventional or Roundup Ready cotton are ALS herbicides such as pyrithiobac (Staple) and trifloxysulfuron (Envoke). Research is already under way investigating Palmer amaranth populations that are likely resistant to both glyphosate and the ALS herbicides, which unfortunately leaves no over-the-top control options in these cotton cultivars. Growers will be forced to rely heavily on at-plant residual herbicides, which can be effective if activated by rainfall or irrigation, but with the slow growth of cotton these at-plant options will likely not provide long-enough control for growers. One study investigated exactly what it would take to remove Palmer amaranth (10% glyphosate resistant and 90% glyphosate sensitive) from a grower's 75-acre field. In that field during 2006, we spent $50 in herbicides plus an additional 220 hours of hand weeding.

## References


Franssen, A.S., D.Z. Skinner, K. Al-Khatib, M.J. Horak, and P.A. Kulakow. 2001. Interspecific hybridization and gene flow of ALS resistance in *Amaranthus* species. *Weed Science* 49:598–606.

Heap, I.M. 2005. *International Survey of Herbicide Resistant Weeds* (http://www.weedresearch.com).

Herbicide Resistant Action Committee (HRAC). 2005. *Guideline to the Management of Herbicide Resistance* (http://www.plantprotection.org/hrac/guideline.html).

Horak, M.J., and T.M. Loughin. 2000. Growth analysis of four *Amaranthus* species. *Weed Science* 48:347–355.

Klingaman T.E., and L. R. Oliver. 1994. Palmer amaranth (*Amaranthus palmeri*) interference in soybeans (*Glycine max*). *Weed Science* 42:523–527.

Massinga, R.A., and R.S. Currie. 2002. Impact of Palmer amaranth (*Amaranthus palmeri*) on corn (*Zea mays*) grain yield and yield and quality of forage. *Weed Technology* 16:532–536.

Massinga, R.A., R.S. Currie, M.J. Horak, and J. Boyer, Jr. 2001. Interference of Palmer amaranth in corn. *Weed Science* 49:202–208.

Morgan, G.D., P.A. Baumann, and J.M. Chandler. 2001. Competitive impact of Palmer amaranth (*Amaranthus palmeri*) on cotton (*Gossypium hirsutum*) development and yield. *Weed Technology* 15:408–412.

Tranel, P.J., J.J. Wassom, M.R. Jeschke, and A.L. Rayburn. 2002. Transmission of herbicide resistance from a monoecious to a dioecious weedy *Amaranthus* species. *Theoretical and Applied Genetics* 105:674–679.

Trucco, F., M.R. Jeschke, A.L. Rayburn, and P.J. Tranel. 2005. Promiscuity in weedy amaranths: High frequency of female tall waterhemp (*Amaranthus tuberculatus*) × smooth pigweed (*A. hybridus*) hybridization under field conditions. *Weed Science* 53:46–54.

Webster, T.M. 2005. Weed survey—Southern states: Broadleaf crops subsection. In *Proceedings of the Southern Weed Science Society* 58:291–304.

# Glyphosate-Resistant Waterhemp: Our Experiences in Missouri

*Kevin Bradley*

Perhaps no single event in the history of agriculture has changed weed management to the extent that Roundup Ready crops have. In 2005, 89% of the soybean acreage in the United States was planted with Roundup Ready soybean varieties, while approximately 36% of the corn acreage was planted with herbicide-resistant corn hybrids, the vast majority of which are also Roundup Ready. Many have speculated that Roundup Ready corn acreage in the U.S. will continue to increase in the next few years, which would place much of the acreage in a Roundup Ready soybean–Roundup Ready corn rotation. And, even though it is hoped that most growers will apply a preemergence herbicide treatment to corn, it is probably safe to assume that the vast majority of the postemergence applications in either Roundup Ready corn or soybeans will involve glyphosate. This scenario represents a tremendous selection pressure that will be placed on weeds to develop resistance to glyphosate.

In fact, in recent years, a number of glyphosate-resistant weed biotypes have already been identified. These resistant species have been identified primarily in locations where a Roundup Ready crop, such as soybean or cotton, has been planted continuously without rotation and where repeated applications of glyphosate have been made year after year. Some of the more recent examples of these species include a number of glyphosate-resistant horseweed, or marestail, biotypes located throughout the central and eastern United States; a glyphosate-resistant common ragweed biotype discovered in Missouri and Arkansas in 2004; glyphosate-resistant Palmer amaranth biotypes discovered in Georgia, Tennessee, and North Carolina in 2005; and glyphosate-resistant common waterhemp biotypes that we discovered in two separate locations in northwestern Missouri, also in 2005.

In 2006, we initiated a number of field experiments on one of these populations in Platte County, Missouri. This population was discovered in fields with a continuous soybean "rotation" in which glyphosate has been used repeatedly as the sole active ingredient since 1996.

In the corn experiments that we have conducted at this site, we have observed excellent waterhemp control with virtually all of our preemergence and preemergence followed by postemergence programs (Table 1). As expected, the glyphosate-only program provided little to no control of the waterhemp. However, postemergence-only programs consisting of two applications of Liberty or Liberty + Atrazine also provided excellent control. We urge growers to use caution in the interpretation of these results, because similar levels of season-long waterhemp control are rarely achieved with these preemergence treatments in other corn fields throughout the Midwest. We attribute the high levels of waterhemp control that we observed in these experiments to the history of the site in question; this location had not been planted in corn and had not received standard applications of preemergence corn herbicides such as atrazine for at least 20 years. We have not observed similar levels of waterhemp control with these same residual treatments in other parts of the state. The results from these experiments reveal a seemingly simple solution to the problem of glyphosate-resistant waterhemp—rotate into corn. However, future research will examine the impact of crop rotation on the stability of glyphosate resistance in the waterhemp population over time.

**TABLE 1 • Influence of preemergence and postemergence herbicide programs on glyphosate-resistant waterhemp control in corn.**

| PRE or E-POST treatments | Postemergence treatments[1] None | Callisto (2 fl oz) | Distinct (4 oz) | Liberty (32 fl oz) | Roundup Omax (22 fl oz) |
|---|---|---|---|---|---|
| | *Common Waterhemp Control 2 Months After Planting*[2] | | | | |
| Degree Xtra (3.7 qt) | 99 a | 99 a | 99 a | 99 a | 99 a |
| Lexar (3 qt) | 97 a | 99 a | 99 a | 99 a | 99 a |
| Atrazine (2 qt) | 99 a | 99 a | 99 a | 98 a | 98 a |
| Radius (22 oz) | 85 b | 98 a | 99 a | 99 a | 99 a |
| Liberty (32 fl oz) | — | — | — | 97 a | — |
| Liberty (32 fl oz) + Atrazine (2 qt) | — | — | — | 99 a | — |
| Roundup Omax (22 fl oz) | — | — | — | — | 25 c |
| Roundup Omax (22 fl oz) + Atrazine (2 qt) | — | — | — | — | 99 a |

[1] Roundup and Liberty POST treatments applied with AMS; Callisto applied with COC and UAN.

[2] Means followed by the same letter are not different (LSD 0.05).

In our soybean experiments, we observed poor control of waterhemp with glyphosate, even at especially high rates (Table 2). In fact, 53% of the waterhemp population survived treatment with 176 fluid ounces of Roundup OriginalMax, indicating that there are a high number of resistant individuals in this waterhemp population. We have also observed poor waterhemp control with other postemergence soybean herbicides such as the protox-inhibiting herbicides Phoenix, Flexstar, Ultra Blazer, and Aim, which suggests to us that we may have resistance to these herbicides in this waterhemp population as well (Table 2, Table 3). The likelihood of protox resistance in addition to glyphosate resistance will be the focus of much greenhouse research that will be conducted in the near future.

As illustrated in Table 3, it seems clear that a program approach that includes an application of a preemergence and a postemergence herbicide will be one of the only effective options for the management of this glyphosate-resistant waterhemp population. Within these programs, the addition of Roundup OriginalMax to a Phoenix or Ultra Blazer treatment did not improve control of glyphosate-resistant waterhemp compared to these treatments alone. Conversely, the addition of Phoenix or Ultra Blazer to a Roundup OriginalMax treatment did not increase control of glypho-

**TABLE 2 • Influence of glyphosate and glyphosate tank-mixes on glyphosate-resistant waterhemp survival 6 weeks after treatment (WAT).**

| Treatments[1] | Rate (product/A) | Waterhemp survival 6 WAT[2,3] (%) |
|---|---|---|
| Roundup OriginalMax | 22 fl oz | 98 a |
| | 44 fl oz | 89 a |
| | 88 fl oz | 63 b |
| | 176 fl oz | 53 b |
| Roundup Omax + Phoenix | 22 fl oz + 8 fl oz | 94 a |
| Roundup Omax + Flexstar | 22 fl oz + ¾ pt | 95 a |
| Roundup Omax + Ultra Blazer | 22 fl oz + 1.5 pt | 95 a |
| Roundup Omax + Aim | 22 fl oz + ¼ fl oz | 97 a |
| Roundup Omax + Firstrate | 22 fl oz + 0.3 oz | 95 a |
| Roundup Omax + Butyrac | 22 fl oz + 2 fl oz | 98 a |

[1] All treatments applied with AMS at 2.5 lb/A.

[2] Number of flagged waterhemp plants/total (total = 80) living 6 weeks after treatment.

[3] Means followed by the same letter are not significantly different (LSD 0.05).

sate-resistant waterhemp compared to the Roundup OriginalMax treatment alone. Based on what we know about the glyphosate resistance in this population and what we suspect about the protox resistance in this population, these results indicate that an effective preemergence herbicide is the most important component. Spartan and Boundary were some of the better preemergence herbicide treatments for glyphosate-resistant waterhemp, but it is important to note that these results are from one year only and that season-long waterhemp control will rarely be achieved with any preemergence soybean herbicide. All postemergence-only treatments provided poor control of glyphosate-resistant waterhemp.

The situation that exists with glyphosate-resistant common waterhemp in Missouri should be viewed as a big, flashing warning sign to any grower in any state who has been planting a continual Roundup Ready crop –soybeans for many years in a row or even to growers who are planting a Roundup Ready soybean–Roundup Ready corn rotation. Also, there is no reason to believe that independent selection events cannot occur throughout different areas, meaning that other farmers who have been in a continuous soybean rotation and who have relied solely on glyphosate may also start to see instances of glyphosate-resistant common waterhemp in their fields as well. The last thing we need in our corn and soybean production systems is to lose the profitability of our current weed management programs as a result of the development of glyphosate-resistant weeds.

Simply put, two alternatives to the problem of glyphosate-resistant weeds exist. Farmers can manage the development of resistance by not spraying glyphosate continually in the same area over time and by rotating to herbicides with other modes of action (proactive resistance management), or farmers can choose to deal with a glyphosate-resistant weed once it occurs by using more expensive weed control measures at that time. The question boils down to "Do I pay a slightly higher price today for weed management strategies that delay or prevent glyphosate resistance or do I pay a much higher price in the future when a glyphosate-resistant weed requires me to use more expensive control measures?"

Recently, some weed scientists have published an interesting study that attempts to address many of these important issues. In that study, the authors found that it would be better economically to proactively manage resistance—or use alternative weed control strategies now in an effort to delay resistance. Some examples of proactive strategies for Midwestern corn and soybean producers who have problems with waterhemp would be, for example, to

- Rotate to conventional corn hybrids and get out of a continuous Roundup Ready soybean rotation if at all possible.
- Use conventional preemergence and/or postemergence herbicide programs that are effective on common waterhemp in corn, given that most producers will

**TABLE 3 • Influence of preemergence and postemergence programs on glyphosate-resistant waterhemp control 3 months after planting.**

| | Postemergence treatments[1] | | | | | |
|---|---|---|---|---|---|---|
| Preemergence treatments | Phoenix | Ultra Blazer | Roundup Omax | Roundup Omax + Phoenix | Roundup Omax + Ultra Blazer | None |
| | *% Waterhemp Control 3 Months After Planting* | | | | | |
| Valor | 68 | 81 | 66 | 86 | 85 | 58 |
| Spartan | 89 | 94 | 91 | 95 | 95 | 80 |
| INTRRO | 76 | 85 | 73 | 86 | 88 | 45 |
| Boundary | 88 | 88 | 81 | 95 | 94 | 80 |
| None | 23 | 23 | 0 | 5 | 3 | 0 |
| LSD (0.05) | | | 12 | | | |

[1] AMS added to all Roundup treatments; NIS added to Phoenix and Blazer treatments when applied alone.

plant Roundup Ready hybrids and utilize glyphosate as the sole herbicide for weed control in soybean.

- In Roundup Ready soybeans, first consider the use of preemergence herbicides that have good activity on common waterhemp (Valor, Spartan, Dual, INTRRO, etc.). The use of an effective postemergence herbicide (Phoenix, Cobra, Reflex, Flexstar, Ultra Blazer) other than glyphosate either applied alone or as a glyphosate tank-mix partner should also be an option (as long as protox resistance is not suspected), but these products are generally more expensive than some of the preemergence options, such as Valor, listed above.

# Predicting the Evolution and Spread of Glyphosate-Resistant Waterhemp

*Patrick J. Tranel*

Since the commercialization of glyphosate-resistant soybean, anecdotal reports of inadequate waterhemp control with glyphosate have steadily increased. However, several factors other than resistance have contributed to the inadequate control. For example, the excellent weed control from glyphosate that farmers observed when first using glyphosate-resistant soybeans probably resulted in some complacency toward glyphosate and, subsequently, in farmers "pushing the system" by applying rates that were too low on plants that were too large. Even in cases where adverse environmental factors and improper application did not appear to account for inadequate waterhemp control with glyphosate, subsequent glyphosate treatment (either in the same season or in the following growing season) typically provided excellent control, ruling out a truly glyphosate-resistant population as the culprit. Consequently, despite anecdotal reports of inadequate waterhemp control with glyphosate, glyphosate resistance in waterhemp had not been confirmed.

This changed in 2005, with the confirmation that a waterhemp population in Missouri was, in fact, resistant to glyphosate. About the same time, populations of Palmer amaranth (a close relative of waterhemp with a more southern distribution) also were confirmed resistant to glyphosate. Details on the glyphosate-resistant waterhemp and Palmer amaranth populations will be provided at other presentations during the conference. Given that we now know glyphosate-resistant waterhemp is a reality, my focus will be, "What can we do to mitigate this threat to our current weed management systems that are reliant (over-reliant) on glyphosate?"

## Two Different Types of Glyphosate-Resistant Waterhemp?

The exact mechanism by which the Missouri waterhemp population is resistant to glyphosate has not yet been determined. Similarly, we do not yet know the genetics of this resistance, including how resistance is passed down from parent to offspring. A relevant observation, however, is that glyphosate resistance is fairly uniform and consistent within the population (i.e., there are few sensitive plants in the population). This observation suggests that the resistance has a simple genetic basis; more specifically, it suggests that a single gene confers the resistance.

In contrast to the single-gene resistance that may be present in the Missouri population, research in my laboratory suggests that glyphosate resistance also can evolve in waterhemp as a multigenic trait. Several of our recommendations for herbicide-resistance mitigation are independent of the underlying genetics of the resistance trait. However, other recommendations depend on whether the resistance is mediated by one or multiple genes. As one example, the strategy of using the maximum labeled use rate to mitigate resistance evolution likely will be much more successful for multigenic resistance than for single-gene resistance. Thus, evidence suggesting that both single- and multi-gene glyphosate resistances can evolve in waterhemp certainly does not help to clarify the debate on how to best mitigate glyphosate resistance.

## Gene Flow in Waterhemp

The genetics underlying a trait (e.g., herbicide resistance) can influence how rapidly that trait spreads via pollen.

Specifically, resistance that is controlled by a single gene will be transferred via pollen flow from one population to another much more rapidly than if resistance is controlled by multiple genes. Gene flow via pollen is particularly significant for a dioecious species such as waterhemp. Being dioecious, waterhemp consists of plants that are either male or female; consequently, waterhemp has evolved mechanisms to increase the probability that pollination will occur even when a female plant does not happen to be growing in immediate proximity of a male plant. Such mechanisms include the small size of the pollen grains (about one-fifth that of corn pollen) and high aperture density (over twice that of most monoecious pigweeds). These characteristics of waterhemp pollen allow it to be carried long distances even at moderate wind speeds. In regard to female waterhemp plants, stigmas remain receptive for several days, increasing the odds that the flowers will be pollinated.

The pollination biology of waterhemp makes legitimate the concern that glyphosate resistance that has evolved in your neighbor's field will become your problem, too. Also, because most herbicide resistances are conferred by single genes, pollen movement among populations readily leads to "stacking" of the different resistances. For example, if you have selected glyphosate-resistant waterhemp in your field, and your neighbor has selected a waterhemp population resistant to PPO inhibitors (e.g., Ultra Blazer), you and your neighbor can expect to have waterhemp resistant to both herbicide groups sooner rather than later. (This, in fact, apparently has already happened in the glyphosate-resistant waterhemp population in Missouri.) Another concern is that waterhemp can hybridize with other pigweed species. Thus, there is the possibility (although it has not been demonstrated yet) that glyphosate resistance in waterhemp could lead to, for example, glyphosate resistance in smooth pigweed.

## Management Recommendations

So what do we do? Well, it might be helpful to remind ourselves of what *not* to do. One thing we have learned from the history of pest management is that over-reliance on a single management tool is a recipe for failure. Increased adoption of glyphosate-resistant corn—and concomitant increased use of glyphosate—will certainly increase the selection intensity for glyphosate-resistant waterhemp and other weeds. The most effective strategy for mitigating glyphosate resistance will be increased use of other weed control strategies. Because of the potential for glyphosate resistance to spread via pollen, even a glyphosate-sensitive female waterhemp plant surviving in your field has the potential to produce glyphosate-resistant progeny. Optimal management of the crop (e.g., pre-plant operations, planting density, spacing, etc.) and use of a soil-residual herbicide will foster a more timely application of glyphosate and thereby reduce the potential for these waterhemp escapes.

# Preparing for the Inevitable—A Prescription for Resistance

*Dawn Nordby*

A little more than ten years have passed since the commercialization of Roundup Ready soybeans and the Monsanto claims that the inactivity of glyphosate in the soil, the maintenance of a gene pool with glyphosate-susceptible traits, and the unique and novel characteristics of glyphosate (combined with more than 20 years of glyphosate use) had not created a resistant plant (Bradshaw et al. 1997). The times have changed, however, and we know for sure that Mother Nature will always find a way.

Since the beginning of chemical control for weeds, researchers from both industry and academia have been presenting their cases and arguing about how to prevent herbicide resistance. Pages could be filled with the numerous suggestions on how to prevent resistance, but there is really only one: never use the herbicide. We have obviously surpassed that mark on the path toward resistance, yet we still have a few other tactics that remain. These tactics can do little to prevent resistance; they can only aid in slowing the spread of herbicide resistance.

The use of soil-applied herbicides is a highly touted tool for slowing resistance; however, the number of acres on which these herbicides have been used has decreased drastically since the introduction of glyphosate-resistant crops. Preemergence herbicides use a different site of action (SOA) than glyphosate, provide residual control, and decrease weed density prior to the postemergence herbicide application. The use of total postemergence herbicide programs with no soil activity does the exact opposite; therefore, we increase our chances of developing resistance.

Another tactic is crop rotation, ideally with the inclusion of a crop other than corn or soybeans and different herbicides used for each crop. The markets and yield tend to dictate the decision of which crop goes in the next year. The Midwest is dominated by a corn–soybean rotation with emphasis on one trait. More than 85% of the soybeans are currently glyphosate resistant, with predictions that more than 50% of the corn planted in Illinois in 2007 will be glyphosate resistant.

Last I checked, a bag of Roundup Ready corn did not state that *only* glyphosate can be applied to this crop, and the same goes for soybeans. The grower and chemical dealer make the choice of which herbicide(s) are used. We can look to our east (Indiana, Ohio, Delaware) and west (Missouri) to the locations where glyphosate-resistant horseweed and waterhemp first occurred in continuous Roundup Ready soybeans. The rotation of continuous glyphosate-resistant crops is no different.

On the other hand, the use of glyphosate-resistant crops has made for some clean fields over the past decade, but those times may be on the way out. The number of weed escapes following postemergence glyphosate applications seems to be on the rise. Debates about the causes of these escapes will continue. Nonetheless, tillage is not being used in most cases to clean up these fields, and a third (or fourth) pass with glyphosate at a higher rate does not always provide control. Gone are the days of cultivation—or are they?

Management of glyphosate resistance varies from grower to grower. Some implement many of these "slow down" tactics in hopes of keeping glyphosate around for a few

more years, while others plant glyphosate-resistant corn and soybeans and use glyphosate exclusively. The development of glyphosate-resistant horseweed (marestail) in this state may change the mind set of these growers. Resistant weeds do not know field boundaries. Take, for example, 100,000 seeds from a single glyphosate-resistant horseweed plant blowing over several miles. Only then may we start thinking about what our neighbors are doing to manage their weeds. Well, that is the case now. No one is exempt form this occurring on his or her farm.

Knowing all this, it might be time to demote glyphosate from its status as a completely safe, fix-all herbicide (Robert and Baumann 1998). The initial benefits of wide application timing and broad-spectrum weed control have been somewhat overshadowed by crop yield loss caused by delayed application timing and the increased frequency of inconsistent weed control. And, with that, the search for the "silver bullet" of weed control will continue.

## References

Bradshaw, L.D., S.R. Padgette, S.L. Kimball, and B.H. Wells. 1997. Perspectives on glyphosate resistance. *Weed Technology* 11:189–198.

Robert, S., and U. Baumann. 1998. Resistance to the herbicide glyphosate. *Nature* 395:2526.

# Soybean Aphid Management: What Works and What Doesn't

*Matt O'Neal, Kevin Johnson, and Nicholas Schmidt*

The year-to-year and within-season variability of soybean aphid make soybean aphid a difficult pest to predict and manage. The current recommendation (Rice et al. 2005) is for soybean growers to scout their soybean fields during the growing season and use an economic threshold to determine the need for a foliar insecticide. Given the recent registration of seed-applied insecticides, such as imidacloprid (Gaucho) and thiamethoxam (Cruiser), for early-season pests such as bean leaf beetles, growers may expect these products to provide protection against soybean aphids. In this summary, we report evaluations of seed treatments in comparison with the current recommendation. Please note that this summary was written before the 2006 yield data were collected; a more complete summary will be reported during the conference.

**TABLE 1 • Insecticide program targeting early season populations of bean leaf beetles.**

| Treatment | Rate[1] | Targeted bean leaf beetles generation/population |
|---|---|---|
| Control | N/A | |
| Thiamethoxam | 50 g per 100 kg | Overwintering |
| Thiamethoxam + lambda-cyhalothrin | 50 g per 100 kg + 3.2 fl oz | Overwintering + first |
| Lambda-cyhalothrin | 2.5 fl oz | Overwintering |
| Lambda-cyhalothrin | 3.2 fl oz | First |
| Lambda-cyhalothrin + lambda-cyhalothrin | 2.5 fl oz + 3.2 fl oz | Overwintering + first |

[1] Seed treatment rates are given as grams formulated product per 100 kilogram seed. Foliar treatment rates are given as fluid ounces formulated product per acre. Foliar-applied insecticide was lambda-cyhalothrin (Warrior 1SC, Syngenta Crop Protection, Greensboro, NC), and the seed

## Do Seed Treatments Prevent Soybean Aphid Outbreaks?

In Iowa, the management of insect pests in soybeans has been complicated by the arrival of the invasive soybean aphid and a recent trend of increasing bean leaf beetle populations leading to economic outbreaks. Several insecticide programs (Table 1) designed to reduce populations of both the overwintering population and first-generation of bean leaf beetle were evaluated during 2004, 2005, and 2006 for their impacts on soybean aphid populations, at three locations across Iowa (Floyd, Story, and Lucas counties; Figure 1). These treatments include seed treatments and foliar insecticides applied to overwintering densities and the first generation of the bean leaf beetle (Table 2).

### *Soybean Aphid Abundance*

In 2004 and 2005, soybean aphids arrived the first week of July in all sites but Floyd County in 2004, where soybean aphids did not arrive until the first week of August. Moreover, in 2005, soybean aphids reached densities over the economic threshold of 250 aphids per plant (O'Neal 2005), in contrast to 2004, when densities did

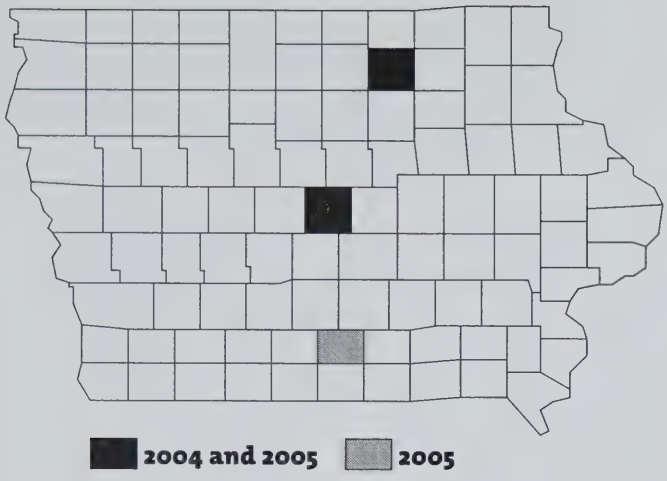


**FIGURE 1 • Experimental locations from north to south: Floyd County, Story County, Lucas County.**

not exceed 100 aphids per plant at the two sites (Figure 2). In 2004, aphids peaked at 64 and 7 aphids per plant at Story and Floyd counties, respectively. In contrast, densities at 2005 study sites ranged from 313, 1,082, and 87 aphids per plant at Story, Floyd, and Lucas counties, respectively. Because densities of soybean aphids were so low in 2004 and there was no impact from any of the treatments on soybean aphid densities or soybean yield, we do not report those data.

### *Estimation of Soybean Aphids Densities*

Densities of soybean aphids (wingless adults, winged adults, and nymphs) were estimated weekly on consecutive plants within each plot. In 2004, soybean aphids were counted on 10 consecutive plants for the entire season. In 2005, the number of consecutive plants on which soybean aphids were counted ranged from 5 to 20, with the number of plants determined by the percentage that were infested with aphids during the previous sampling date. When 0% to 80% of plants were infested with soybean aphids, soybean aphids were counted on 20 plants. When 81% to 99% of plants were infested, aphids on 10 plants were counted. If all plants were infested, soybean aphids on only 5 plants were counted.

The seasonal exposure of soybean to "cumulative aphid days" was calculated based on the number of aphids counted per plant on each sampling date. Exposure of soybean plants to soybean aphids between two sampling dates (the "aphid days") was calculated with the following equation:

$$\sum_{n=1}^{\infty} = \left( \frac{x_{i-1} + x_i}{2} \right) \times t,$$

where $x$ is the mean number of aphids on sample day $i$, $x_{i-1}$ is the mean number of aphids on the previous sample day, and $t$ is the number of days between samples $i-1$ and $i$. Summing the aphid days accumulated during the growing season (cumulative aphid days) provides a measure of the seasonal aphid exposure that a soybean plant experienced (E. Hodgson, unpublished data). Cumulative aphid days are reported as season-long totals for all experiments.

### *Results*

In 2005, there was little overlap of either the overwintering population or the first generation of bean leaf beetle with soybean aphids because aphid densities did not reach economic levels until early August (Figure 2). During 2005, insecticides that were used against the overwintering population or the first generation of bean leaf beetle did not prevent economic populations of soybean aphids or consistently reduce densities compared with control treatments. Interestingly, the greatest densities of soybean aphids occurred when a low rate of lambda-cyhalothrin (178 mL/ha) was applied to the overwintering population of bean leaf beetles (Table 3). Although there were differences in soybean exposure to soybean aphid in 2005, there were no differences in yield (Figure 3).

**TABLE 2 • Dates of insecticide application program targeting early season populations of bean leaf beetles.**

| | | | Foliar insecticide application date | |
|---|---|---|---|---|
| Year | County | Planting date | Overwintering population | First generation |
| 2004 | Floyd | May 3 | May 19 | July 8 |
| | Story | April 28 | May 20 | July 4 |
| 2005 | Floyd | May 22 | June 1 | June 22 |
| | Story | May 23 | June 7 | June 21 |
| | Lucas | May 5 | June 2 | June 23 |

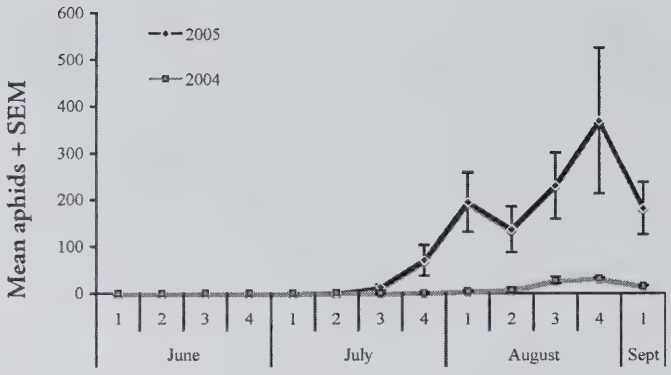


**FIGURE 2 • Mean soybean aphids ± standard error of mean of all locations in Iowa by year.**

## The Importance of Treatment Timing for Soybean Aphid Management

The majority of foliar insecticides labeled for use against soybean aphids in North America are organophosphates and pyrethroids. These insecticides are toxic to a wide range of insects (referred to as "broad spectrum"), including pests and beneficial species alike, such as ladybird beetles. Reduced-risk insecticides may eliminate the negative impact of insecticides on the predators of soybean aphids. The loss of these predators may help explain why applications of a foliar insecticide in June may result in greater aphid densities than observed in untreated plots (Table 3).

The EPA defines a reduced-risk pesticide as one that "may reasonably be expected to accomplish one or more of the following: (1) reduces pesticide risks to human health; (2) reduces pesticide risks to nontarget organisms; (3) reduces the potential for contamination of valued, environmental resources; or (4) broadens adoption of IPM or makes it more effective" (EPA 1998).

There are two classes (neonicotinoids and pymetrozines) of insecticides that are lethal to soybean aphids and may be considered reduced risk. Neonicotinoid insecticides may be considered reduced risk due to their mode of exposure as a plant systemic insecticide. Pymetrozine, although not labeled for use in soybean, is a plant systemic insecticide with a specific mode of action (targeting the cibarial pump) that has been shown to have limited impacts on beneficial insects, including aphid predators (Harrewijn and Kayser 1997; Sechser et al. 2002; Torres et al. 2003). It is not known what the impact of putative (imidacloprid) and expected (pymetrozine) reduced-risk, foliar-based insecticides may have on the natural enemy complex of soybean aphids.

We evaluated whether insecticides applied within an IPM framework (based on scouting and use of an economic threshold) would provide greater yield protection than use of preventive seed treatments (Table 4). In 2005 (Floyd County) and 2006, we conducted experiments to address this question. The experiment included six treatments (including control) that compared preventive seed treatments to foliar insecticide treatments applied when densities of soybean aphids reached 250 aphids per plant. Foliar insecticides lambda-cyhalothrin, pymetrozine (Fulfill) and imidacloprid (Trimax) were compared with seed treatments, thiamethoxam at 50 g per 100 kg seed and 100 g per 100 kg seed, and imidacloprid (Gaucho) at 62.5 g per 100 kg seed (see Table 4 for rates and manufacturer information). Imidacloprid is commercially available as both a seed treatment (Gaucho) and a foliar insecticide (Trimax, expected commercial release in spring 2007). The two imidacloprid treatments allowed for a direct comparison of an insecticide applied as a preventive seed treat-

**TABLE 3 • Peak populations of soybean aphids in during 2005 bean leaf beetle experiment.**

| Treatment | Targeted bean leaf beetle generation/population | Peak population[1] at each county ± SEM | | |
|---|---|---|---|---|
| | | Floyd | Story | Lucas |
| Control | Overwintering | 507 ± 81 | 281 ± 82 | 87 ± 14 |
| Thiamethoxam | Overwintering | 758 ± 204 | 302 ± 61 | 46 ± 7 |
| Thiamethoxam + lambda-cyhalothrin | Overwintering First | 828 ± 270 | 233 ± 62 | 54 ± 11 |
| Lambda-cyhalothrin | Overwintering | 1082 ± 275 | 245 ± 40 | 65 ± 7 |
| Lambda-cyhalothrin | First | 485 ± 148 | 312 ± 56 | 56 ± 8 |
| Lambda-cyhalothrin + lambda-cyhalothrin | Overwintering First | 421± 67 | 313 ± 93 | 54 ± 9 |

[1] Peak population occurred on August 25, 29, and 18 for Floyd, Story, and Lucas counties, respectively.

ment and also as a foliar insecticide. Thiamethoxam and lambda-cyhalothrin are both commercially available to growers for soybean aphid control in soybeans at the rates used. Pymetrozine is not labeled for either use in soybean.

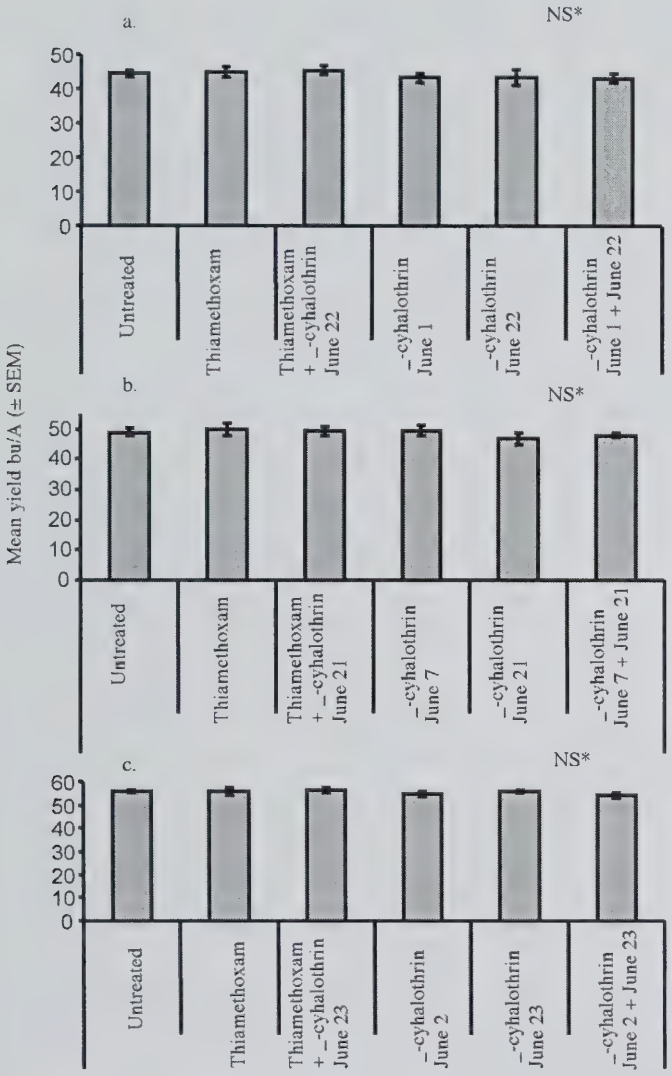


**FIGURE 3 • 2005 yield for the multi-pest management at Floyd County (a), Story County (b), and Lucas County (c).**

Thiamethoxam was applied at planting, and lambda-cyhalothrin treatments were applied based on the emergence of the overwintering, first, or both generations of bean leaf beetles. Dates varied across locations due to timing of bean leaf beetle emergence. Foliar-applied insecticide was lambda-cyhalothrin (Warrior, lambda-cyhalothrin, Syngenta Crop Protection, Greensboro, NC), and the seed treatment insecticide was thiamethoxam (Cruiser, thiamethoxam, Syngenta Crop Protection, Greensboro, NC). Plots were planted on May 22 at Floyd County, on May 23 at Story County, and on May 5 at Lucas County.

The use of pymetrozine was included to address a subobjective in the insecticide-timing experiment. Pymetrozine has a Homopteran-selective mode of action that reduces the impact on the beneficial insect community (Sechser et al. 2002; Torres et al. 2003; Banks and Stark 2004). With an increasing body of research suggesting that predatory insects are capable of significantly reducing soybean aphid densities, there is an increasing level of interest in diminishing the negative impact of broad-spectrum insecticides on the predatory insect community (Fox et al. 2004, 2005; Rutledge et al. 2004; Rutledge and O'Neal 2005; Mignault et al. 2006). In 2005, we evaluated the potential reduction in flaring of soybean aphid densities when using a more specific insecticide, pymetrozine.

Treatments were arranged in a randomized complete block design with six replications. Plots measured 5 by 31 meters, and were established using conventional production practices. Soybeans (variety NK S24-K4 RR) were planted in 76-centimeter rows at a population of 456,000 seeds per hectare (190,000 seeds per acre) using a no-till planter on May 22. Foliar insecticides were applied with a backpack sprayer using volumes of 237 liters per hectare (20 GPA) at a pressure of 274 KPA (40 psi).

Insecticides applied on August 2, 2005, had a significant impact on plant exposure levels to soybean aphids. Soybean aphid densities averaged 211 ± 48 (mean number of soybean aphids in nonseed-treated plots) per plant (across all nonseed treatments) at the time of the foliar insecticide application (August 2). However, soybean aphid densities quickly surpassed the economic threshold of 250 soybean aphids per plant in the control (266 ± 54 soybean aphids per plant) by August 4. In 2005, populations peaked at 1,331 ± 323 soybean aphids per plant on August 25 in the insecticide timing experiment in Floyd County. In 2005, the soybean aphid infestation significantly affected yield when soybeans were left untreated (Figure 2). The foliar insecticide lambda-cyhalothrin provided the greatest reduction in soybean aphid exposure (97.5%) and the greatest level of yield protection (13% above the control; Figure 4). The seed treatment imidacloprid provided the lowest level of soybean aphid control (12% reduction) and the lowest yield benefit compared with the control (3%). When compared with the untreated controls, foliar applications of pymetrozine and imidacloprid provided an intermediate level of protection both in terms of soybean exposure to soybean aphids (89% and 86% reductions in exposure, respectively; Figure 4) and yield (9% and 8%

**TABLE 4 • Products and rates for 2005 insecticide timing experiment.**

| Treatment | Active ingredient | Rate[1] |
|---|---|---|
| Control | — | — |
| Thiamethoxam | Cruiser 5 FS | 50 g per 100 kg |
| Thiamethoxam | Cruiser 5 FS | 100 g per 100 kg |
| Imidacloprid | Gaucho 480 F | 62.5 g per 100 kg |
| Imidacloprid | Trimax 4 E | 1.5 fl oz |
| Pymetrozine | Fulfill 50WG | 2.3 oz |
| Lambda-cyhalothrin | Warrior 1 SC | 3.2 fl oz |

[1] Seed treatment rates are given as grams formulated product per 100 kilogram seed. Foliar treatment rates are given as formulated product per acre. Seed treatments Cruiser (thiamethoxam, Syngenta Crop Protection, Greensboro, NC) and Gaucho (imidacloprid, Bayer CropScience, Research Triangle Park, NC) were applied as a seed treatment at planting on May 22. Foliar treatments Trimax (imidacloprid, Bayer CropScience, Research Triangle Park, NC), Fulfill (pymetrozine, Syngenta Crop Protection, Greensboro, NC), and Warrior (lambda-cyhalothrin, Syngenta Crop Protection, Greensboro, NC) were applied on August 2, and aphid populations averaged 211 soybean aphids per plant at application.

improvement in yield, respectively; Figure 5). The foliar application of imidacloprid resulted in a greater reduction in soybean aphid exposure levels then when it was utilized as a seed treatment (83% reduction compared with the seed treatment of imidacloprid; Figure 4). The foliar application of imidacloprid also led to greater yield protection than when imidacloprid was applied as a seed treatment (6 % improvement; Figure 5).

## Conclusion

Foliar insecticides, when applied within an IPM framework (use of an economic action level of 250 soybean aphids per plant) reduced aphid exposure and protected yields more effectively than use of preventive insecticide applications such as seed treatments. A foliar formulation of imidacloprid, applied at an economic threshold of 250 soybean aphids per plant, reduced the exposure of soybeans to aphids and resulted in a greater yield benefit than when it was applied as a preventive seed treatment. For the prevention of soybean yield loss caused by soybean aphids, the use of a preventive insecticide program did not provide better protection compared with a single foliar insecticide application based on the use of an economic threshold.

## References


Banks, J.E., and J.D. Stark. 2004. Aphid response to vegetation diversity and insecticide applications. *Agriculture Ecosystems & Environment* 103:595–599.

Environmental Protection Agency (EPA). 2006. Food Quality Protection Act (FQPA) of 1996. http://www.epa.gov/pesticides/regulating/laws/fqpa.

Fox, T.B., D.A. Landis, F.F. Cardoso, and C.D. Difonzo. 2004. Predators suppress *Aphis glycines* Matsumura population growth in soybean. *Environmental Entomology* 33:608–618.

Fox, T.B., D.A. Landis, F.F. Cardoso, and C.D. Difonzo. 2005. Impact of predation on establishment of the soybean aphid, *Aphis glycines* in soybean, *Glycine max*. *Biocontrol* 50:545–563.

Harrewijn, P., and H. Kayser. 1997. Pymetrozine, a fast-acting and selective inhibitor of aphid feeding. In-situ studies with electronic monitoring of feeding behavior. *Pesticide Science* 49:130–140.

Mignault, M.P., M. Roy, and J. Brodeur. 2006. Soybean aphid predators in Québec and the suitability of *Aphis glycines* as prey for three Coccinellidae. *Biocontrol* 51:89–106.

O'Neal, M.E. 2005. Insecticide use for soybean aphid control up again in 2005. *Integrated Crop Management Newsletter*. Iowa State University, Department of Entomology, Ames, Iowa IC-494 (21).

Rice, M.E., M.E. O'Neal, and P. Pedersen. 2005. *Soybean Aphids in Iowa—2005*. Iowa State University, University Extension Publication No., SP-247.

Rutledge, C.E., and R.J. O'Neil. 2005. *Orius insidiosus* (Say) as a predator of the soybean aphid, *Aphis glycines* Matsumura. *Biological Control* 33:56–64.

Rutledge, C.E., R.J. O'Neil, T.B. Fox, and D.A. Landis. 2004. Soybean aphid predators and their use in integrated pest management. *Annals of the Entomological Society of America* 97:240–248.

Sechser, B., B. Reber, and F. Bourgeois. 2002. Pymetrozine: Selectivity spectrum to beneficial arthropods and fitness for integrated pest management. *Anzeiger für Schädlingskunde—Journal of Pest Science* 75:72–77.

Torres, J.B., C.S.A. Silva-Torres, and J.V. de Oliveira. 2003. Toxicity of pymetrozine and thiamethoxam to *Aphelinus gossypii* and *Delphastus pusillus*. *Pesquisa Agropecuaria Brasileira* 38:459–466.

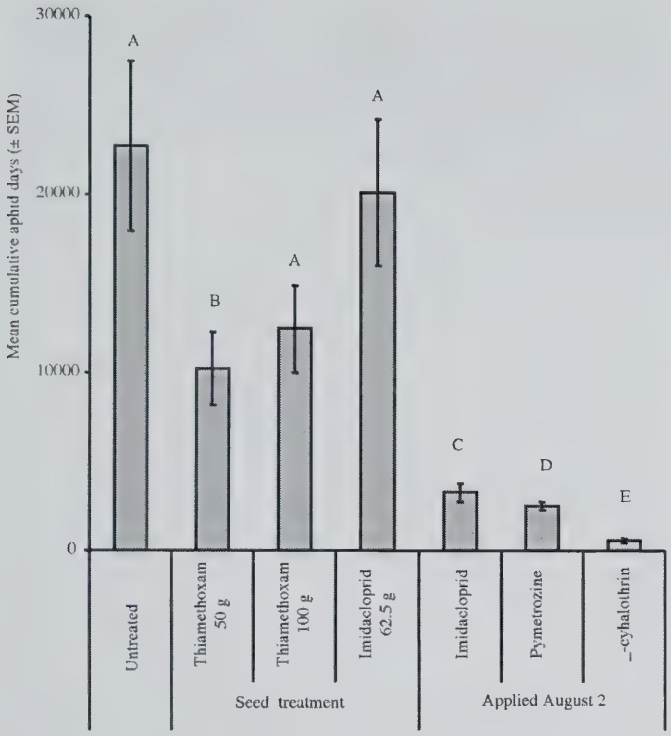


**FIGURE 4 • Comparison of seed- and foliar-applied insecticides on soybean exposure to soybean aphids based on average cumulative aphid day measurements at the Floyd County site in 2005.**

Soybean were planted on May 22. Seed treatments Cruiser (thiamethoxam, Syngenta Crop Protection, Greensboro, NC) and Gaucho (imidacloprid, Bayer CropScience, Research Triangle Park, NC) were applied as a seed treatment. Foliar treatments Trimax (imidacloprid, Bayer CropScience, Research Triangle Park, NC), Fulfill (pymetrozine, Syngenta Crop Protection, Greensboro, NC), and Warrior (lambda-cyhalothrin, Syngenta Crop Protection, Greensboro, NC) were applied on August 2, and aphid populations averaged 211 soybean aphids per plant at the time of application. Means labeled with a unique letter were significantly different ($P < 0.05$).

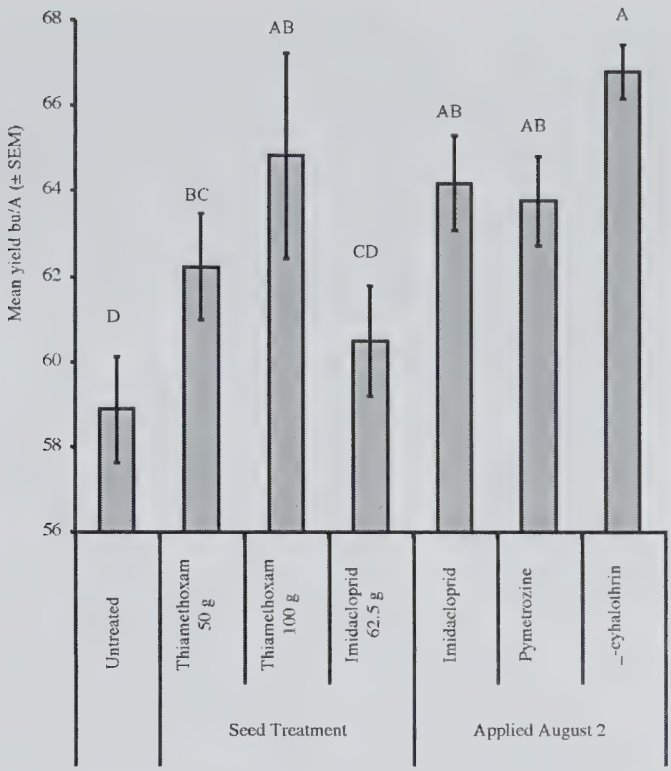


**FIGURE 5 • Comparison of seed- and foliar-applied insecticides on soybean exposure to *A. glycines* based on yield (kilograms per hectare) at Floyd County in 2005.**

Soybeans were planted on May 22. Foliar treatments imidacloprid (Trimax, Bayer CropScience, Research Triangle Park, NC), pymetrozine (Fulfill, pymetrozine, Syngenta Crop Protection, Greensboro, NC), and lambda-cyhalothrin (Warrior, Syngenta Crop Protection, Greensboro, NC) were applied on August 2. Mean aphid populations were 211 soybean aphids per plant at the time of application. Means labeled with a unique letter were significantly different ($P \leq 0.05$).

# Western Bean Cutworm and the Invasion of Illinois Corn: It's Like Déjà vu All Over Again

*Marlin E. Rice*

The western bean cutworm—a major pest of corn in Colorado and Nebraska—was not a pest of Illinois corn during the previous century (Steffey et al. 1999). It was first detected in Illinois in 2004 (Dorhout and Rice 2004) and now occurs in at least 49 Illinois counties. The western bean cutworm is not the first insect to successfully invade Illinois crops. During the last 70 years, notable pest movements into the state include the European corn borer in 1939 (Mason et al. 1996), the western corn rootworm in 1964 (Metcalf 1983), and, more recently, the soybean aphid in 2000 (Gray 2000). Illinois growers or crop advisors are now experiencing the western bean cutworm for the first time, but if they feel like they've been in this situation before, then maybe they can relate to Yogi Berra when he said, "This is like déjà vu all over again."

The western bean cutworm, *Striacosta albicosta* (Lepidoptera: Noctuidae), is native to North America. It was first reported as a pest of Colorado pinto beans in 1915. In 1935, adults were captured in western Nebraska (Hagen 1963) and, later, in 1954, it was identified as a pest of corn in southern Idaho (Blickenstaff 1979). Since its discovery in the late 1880s, it has slowly and steadily expanded its known distribution eastward from Arizona to Iowa (Rice 2000) and Minnesota (O'Rourke and Hutchison 2000). The western bean cutworm was known to occasionally occur in western Iowa prior to 1970, but it was not until 2000 that an economically damaging population was found in field corn. Since then, it has become an annual economic pest in western and central regions of the state. In 2004, western bean cutworms were collected in pheromone traps for the first time in Illinois and Missouri.

## Description

### *Eggs*

Western bean cutworm eggs are nearly round with small ridges extending from the top to the bottom of the egg. Eggs are laid in tightly packed, irregularly shaped clusters from 21 to 195 eggs (Hagen 1962). An average cluster has 52 eggs. Eggs are white when first laid and turn dark purple a day or two before hatching.

### *Larvae and Pupae*

Newly hatched larvae are a dull orange color with black heads and a black pronotum (hardened plate immediately behind the head). They have eight to ten black spots on each body segment. Mature larvae have a broad, faint tan stripe along the back, gray sides, no distinctive spots, and an orange head. The pronotum has two broad brown stripes. The brown stripes on the pronotum are a good characteristic to distinguish western bean cutworms from other corn caterpillars. Mature larvae are about 1½ inches long. There are six, occasionally seven, larval stages. Pupae are orange-brown in color, occur in the soil, and are rarely seen.

### *Adults*

The adult moth is ¾-inch long and a mixture of brown, gray, and cream colors. Each forewing has a broad, cream-colored stripe along the front edge of the wing and two distinctive markings—a small, light-colored circular spot just behind and halfway along the stripe, and a buff-colored, boomerang-shaped spot near the end of the stripe. The hindwings are light tan with no distinct pattern.

## Life History in Corn

In western Iowa, adult flight begins in late June, peaks in mid- to late July, and ends during mid-August (Table 1). The female emits a mating pheromone that attracts males. One to five days after mating, female moths begin laying their eggs on the upper surface of the topmost corn leaves, especially on the flag leaf. Moths are most attracted to cornfields with tassels just beginning to emerge for egg laying. Females average 407 eggs laid during their brief lifetime. Eggs hatch in 5 to 7 days. Newly hatched larvae feed on the tassel, corn pollen, tissue behind the leaf sheaths, and silks The fourth and fifth instars cut entrance holes through the husks and feed on the developing kernels (Hagen 1962). Each of the first five larval stages takes about 5 to 6 days to develop, with the sixth and seventh instars averaging 7 and 10 days, respectively. Unlike corn earworms, western bean cutworms are not cannibalistic, so several larvae may feed in the same ear. Six larvae per ear have been found in Iowa and 20 larvae per ear have been reported from Nebraska (Seymour et al. 2004). After larvae finish feeding, they chew through the cornhusk, crawl to the ground, and form a chamber 3 to 8 inches deep in the soil. Here the prepupal stage overwinters. Pupation occurs during late May in Nebraska (Hagen 1962). Adults begin to emerge in early summer. There is one generation a year.

Soil type and moisture in Nebraska have influenced western bean cutworm populations. Sandy soils tended to have larger populations compared to clay soils. Soil moisture, from either rainfall or irrigation, is necessary for adult emergence from their pupal cells and can be a limiting population factor, especially in clay soils.

## Damage to Corn

Newly hatched larvae feed in one of two places, depending on the stage of corn development. In pretassel-stage corn, the larvae penetrate the flag leaf and feed on pollen in the developing tassel. In tassel-stage corn, larvae feed on shed pollen, leaf tissue, and silks and eventually move to the kernels. Extensive feeding on the silks during pollination may result in incomplete kernel set.

The corn ear is the primary feeding site for larvae. Larvae enter the ear by chewing through the husk or the silks (Hagen 1962). Unlike corn earworms, which restrict most of their feeding to the ear tip, western bean cutworms feed on developing kernels in the ear tip, middle of the ear, and ear butt (Figure 1). This injury to developing kernels can result in constricted and deformed ears, particularly when larvae feed on milk-stage kernels. Yield losses from one larva per corn plant at dent stage were estimated at 3.7 bushels per acre in Nebraska (Seymour et al. 2004), while ears with single larvae in Iowa showed 4.1% to 10.9% yield loss per ear during 2006. In Colorado, yield reductions of 30% to 40% have been noted from heavily infested ears. In addition to this loss of grain, ear molds may develop on the kernels, further reducing the yield quality at harvest.

**FIGURE 1 • Corn ear damaged by single western bean cutworm larva.**

## Movement Across the Midwest

Prior to 2000, the western bean cutworm was considered to be extremely rare in Iowa, and economic damage (i.e., losses exceeding the economic threshold) had never been reported. The first significant damage was observed in 2000 in a cornfield at Holstein (Rice 2000). This western Iowa field had approximately 95% of the ears heavily damaged. Two years later, larvae or their damage could be found in most western Iowa counties, and adult moths were being collected in blacklight traps in central Iowa. In 2004, pheromone traps were placed throughout eastern Iowa, including counties bordering the Mississippi River. Adult moths were collected in every trap placed in eastern Iowa,

**TABLE 1 • Four-year blacklight captures of western bean cutworm adults in Woodbury County, Iowa, 2002–2005.**

| | Western bean cutworm adults | | | |
|---|---|---|---|---|
| Year | First capture | Peak capture | Last capture | Total |
| 2002 | June 28 | July 13 | August 11 | 12,739 |
| 2003 | July 10 | August 1 | August 17 | 244 |
| 2004 | July 5 | July 23 | August 10 | 531 |
| 2005 | June 28 | July 13 | August 10 | 1,328 |

and the insect was assumed to occur in every Iowa county.

Pheromone traps also were placed for a single night in July 2004 in northeastern Missouri and west central Illinois counties near Iowa. Western bean cutworm adults were trapped in Warren County, Illinois, and Harrison and Putnam counties in Missouri (Dorhout and Rice 2004). These captures were the first documented occurrence of this insect in these two states and represented a significant southeastern movement of the insect from its previously known distribution.

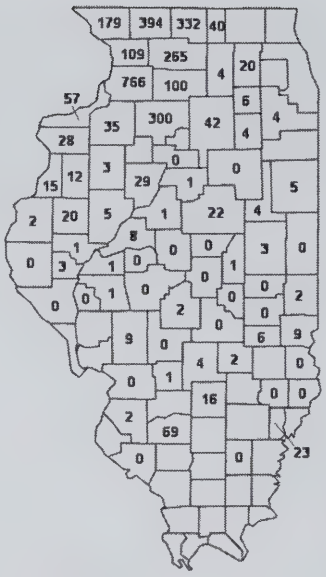


**FIGURE 2 • Captures of western bean cutworm adults in pheromone traps, Illinois, 2006.**

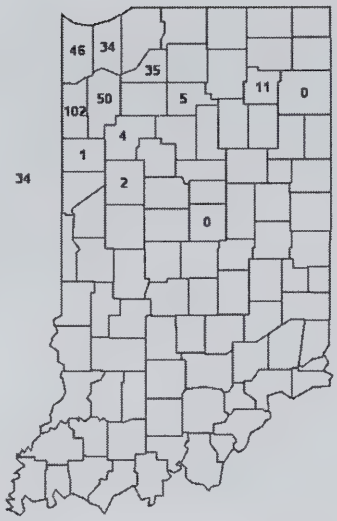


**FIGURE 3 • Indiana.**

**FIGURE 4 • Ohio.**

The following year, pheromone traps were placed throughout northern Illinois to monitor what was believed to be a continuing range expansion of this insect. But in Illinois, the eastern limits of the distribution could not be defined—traps captured moths on the Indiana state line. The trapping effort was then expanded eastward in 2006, and, in cooperation with extension entomologists and seed companies, pheromone traps were placed throughout northern Indiana and central Ohio.

Reports of trap captures in 2006 indicated that the five Illinois counties with the highest populations were Whiteside, Stephenson, Winnebago, Bureau, and Ogle, respectively (Figure 2) (Iowa State University 2006). The potential for economic damage was probably the greatest in these fields during 2006, but traps do not necessarily reflect the populations throughout the county, so economic damage could have occurred in some counties with low trap captures. Additionally, trap capture data are not always good indicators of economic damage in the field.

The western bean cutworm continued its march across Illinois to the east. Moths were trapped in 10 of 12 Indiana counties, with a Newton County trap capturing 102 adults (Figure 3). Surprisingly, adults also were reported to be trapped in western Ohio in Fulton, Shelby, and Van Wert counties (Figure 4). The Ohio captures probably represent the most easterly distribution of this insect in the Corn Belt because no moths were reported from traps in Clark, Crawford, Franklin, Licking, Pike, Wayne, and Wood counties.

## Scouting

Scouting is a primary management tactic for this insect, and it can be initiated by using either degree days or trap catches. Degree days (base 50°F) for 25%, 50%, and 75% adult emergence are 1,319, 1,422, and 1,536, respectively (Ahmad 1979). Adult populations also can be monitored using a blacklight trap or a commercial brand (i.e., Scentry) western bean cutworm pheromone. A common trapping procedure is to cut out windows on the upper half of a plastic 1-gallon milk jug. The pheromone is suspended inside the milk jug. The jug is filled with a 4:1 mixture of soapy water and antifreeze that kills and preserves any captured specimens. The trap can then be placed on a post 3 to 4 feet high near a cornfield.

Start scouting for western bean cutworm eggs in corn when moths are first captured (Seymour et al. 2004) or at 25% predicted adult emergence. Peak adult capture, and probably egg laying, occurs about 2 to 3 weeks after the first adult capture (Table 1). Inspect the upper three to four leaves on 20 consecutive plants at five locations. Hybrids in different stages of development or different leaf characteristics (upright vs. open) should be scouted separately because adult moths may be more attracted

**TABLE 2 • Economic injury levels (eggs per plant) for western bean cutworm in dent stage corn.[1]**

| Corn value ($/bu) | Control costs ($/A) | | | | |
|---|---|---|---|---|---|
| | $8 | $10 | $12 | $14 | $16 |
| $2.00 | 33 | 41 | 49 | 57 | 65 |
| $2.25 | 29 | 37 | 44 | 51 | 57 |
| $2.50 | 26 | 33 | 40 | 46 | 52 |

[1] Modified from Appel et al. 1993.

to one hybrid than the other. A nominal threshold recommended by the University of Nebraska is 8% of the plants with eggs or young larvae found on the flag leaf or in the tassel (Seymour et al. 2004). A simple economic threshold that considers the value of corn and the cost of the insecticide application is shown in Table 2. The values in this table, based on research conducted at the University of Nebraska, assume 3.3% survival of the eggs. Of these two thresholds, the 8% infested plant threshold is more commonly used, but the relative accuracy of one method over the other is unknown.

## Management

### *Insecticides*

Timing of an insecticide application is critical. If the tassel has not emerged when the larvae hatch, they will move into the whorl and feed on the developing pollen grains in the tassel. As the tassel emerges, the larvae will move down the plant to the green silks and then into the silk channel to feed on the developing ear. Once the larvae reach the ear tip and enter the silks, effective control with an insecticide is nearly impossible. Seymour et al. (2004) state that if the eggs have hatched, insecticide applications should be made after 95% of the plant tassels have emerged but before larvae enter the silks. If the eggs have not hatched and plants have tasseled, time the insecticide to when most of the eggs are expected to hatch. Eggs that are dark purple will hatch within a day.

If an insecticide application is needed, cornfields should be checked for the presence of spider mite colonies. If mites are found, select a product that does not stimulate mite reproduction. Products that contain permethrin (Pounce, Ambush) or esfenvalerate (Asana) have been associated with increased mite reproduction. Other products labeled for western bean cutworm control on corn include Capture 2EC, Lorsban 4E, Penncap-M, Sevin XLR Plus, and Warrior 1EC.

### *Transgenic Corn*

Transgenic corn is available with control against several species of caterpillars (Table 3).

In 2006, corn hybrids were evaluated at three locations in northwestern Iowa for performance against western bean cutworm. Each ear was divided into four equal quadrates (looking down from the tip of the ear), and the length of damage was measured in centimeters, with damage from all quadrates combined per ear. A minimum of 20 ears per hybrid were examined at each location. Field observations indicate that Herculex I or Herculex Xtra provided the best level of protection against western bean cutworm (Table 4), and it was consistently better than YieldGard Corn Borer hybrids in providing protection (Tables 4–6). Hercules does not provide complete protection against western bean cutworm damage, but the amount of damage was very small when compared to damage on YieldGard ears at all locations and across all hybrids (Table 6). Based on these data, only corn with the Bt protein Cry1F offered in Herculex I or Herculex Xtra hybrids have the potential to control western bean cutworms.

**TABLE 3 • Pest control spectrum of Bt corn for Lepidoptera[1].**

| Product | Event/gene | Western bean cutworm | European corn borer | Corn earworm | Armyworm | Fall armyworm | Black cutworm |
|---|---|---|---|---|---|---|---|
| Herculex[2] | TC1507Cry1F | Control | Control | Suppression | Not labeled | Control | Control |
| YieldGard | Mon810Cry1Ab | Not labeled | Control | Suppression | Not labeled | Suppression | Not labeled |
| YieldGard | Bt11 Cry1Ab | Not labeled | Control | Suppression | Not labeled | Suppression | Not labeled |

[1] As stated by seed industry literature.

[2] Includes Herculex I and Herculex Xtra.

**Table 4. Western bean cutworm damage to Herculex I, Herculex Xtra, and YieldGard Corn Borer hybrids at three Iowa locations, 2006.**

| Location | Company | Hybrid | Trait | Mean cm damage/ear[1,2] |
|---|---|---|---|---|
| Laurens | Mycogen | 2J454 | — | 5.60 a |
| | Northrup King | N51-T8 | YG-CB | 4.88 ab |
| | Mycogen | 2D545 | — | 4.73 ab |
| | Northrup King | N46-J7 | YG-CB | 4.55 ab |
| | Mycogen | 2E522 | — | 3.93 abc |
| | Northrup King | N51-V9 | YG-CB | 3.70 abc |
| | Mycogen | 2J525 | — | 3.03 bcd |
| | Northrup King | N36-R6 | YG-CB | 3.00 bcd |
| | Northrup King | N53-U1 | YG-CB | 2.45 cd |
| | Garst | 8693 | YG-CB | 2.38 cd |
| | Garst | 8880 | YG-CB | 1.45 de |
| | Garst | 8534 | YG-CB | 1.38 de |
| | Mycogen | 2A498 | — | 1.38 de |
| | Mycogen | 2G677 | HX-X | 0.10 e |
| | Mycogen | 2R570 | HX-I | 0.03 e |
| Mallard | Mycogen | 2K541 | YG-CB | 4.08 a |
| | Mycogen | 2D545 | — | 3.08 a |
| | Mycogen | 2E633 | HX-I | 1.35 b |
| | Mycogen | 2D555 | HX-I | 0.43 bc |
| | Mycogen | 2R570 | HX-I | 0.35 bc |
| | Mycogen | 2E526 | HX-X | 0.10 c |
| | Mycogen | 2J527 | HX-I | 0.05 c |
| Rembrandt | Mycogen | 2K541 | YG-CB | 5.00 a |
| | Mycogen | 2D545 | — | 4.53 a |
| | Mycogen | 2E522 | — | 4.30 a |
| | Mycogen | 2J665 | — | 1.05 b |
| | Mycogen | 2E633 | HX-I | 0.20 b |
| | Mycogen | 2D555 | HX-I | 0.00 b |
| | Mycogen | 2D673 | HX-I | 0.00 b |
| | Mycogen | 2P722 | HX-I | 0.00 b |
| | Mycogen | 2R570 | HX-I | 0.00 b |

[1] Means at the same location and followed by the same letter are not statistically significant by ANOVA, $P = 0.05$.

[2] $n = 20$ ears per hybrid except Mallard, Mycogen 2K541, $n = 60$ ears.

An interesting find in two of the three locations was that YieldGard Corn Borer hybrids had more kernel damage than the untreated check hybrids (Table 5). Data are still being analyzed as of this writing, but experiments at Iowa State University suggest that a YieldGard Corn Borer hybrid changes the ratio, or proportion, of caterpillar species that attack YieldGard hybrids, thereby indirectly favoring the western bean cutworm and allowing it to cause more damage in a YieldGard hybrid than in a near-isogenic corn hybrid without the Bt protein. This phenomenon, known as pest replacement (Pedigo and Rice, 2006), may be a partial explanation for the increased damage to corn in the Midwest and range expansion of the western bean cutworm.

## The Future

The western bean cutworm appears to be firmly established as a pest of Illinois field corn. Its movement into Indiana and Ohio was unexpected yet not surprising, considering the adaptive ability of many pest insects (i.e., western corn rootworm, European corn borer, soybean aphid) to expand their range. Whether the western bean cutworm will become a significant pest in Illinois, Indiana, or Ohio can only be answered in the future. However, the damage potential represented by this species strongly suggests that it should not be ignored, nor should fear of economic damage be an immediate reason to invest in increased acres of transgenic Bt corn. Fortunately, corn growers have a primary tool at their disposal to manage the western bean cutworm should it reach economically damaging levels—scouting combined with a properly timed insecticide. If the western bean cutworm does become an established, economically damaging pest in the state, then growers should consider an additional pest management tool—planting transgenic Herculex I or Herculex Xtra corn hybrids.

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## References

Ahmad, T.R. 1979. Comparison of heat unit accumulation methods for predicting European corn borer and western bean

**TABLE 5 • Western bean cutworm damage (summarized by location) to Herculex[1] and YieldGard Corn Borer hybrids, Iowa, 2006.**

| Location | Trait | Ears examined | Mean ± S.E. cm damage/ear[2] |
|---|---|---|---|
| Laurens | Herculex I | $n = 40$ | 0.06 ± 0.54 b |
| | YieldGard CB | $n = 160$ | 2.97 ± 0.27 a |
| | Check | $n = 100$ | 3.73 ± 0.34 a |
| Mallard | Herculex I | $n = 100$ | 0.46 ± 0.20 c |
| | YieldGard CB | $n = 60$ | 4.08 ± 0.44 a |
| | Check | $n = 20$ | 3.08 ± 0.34 b |
| Rembrandt | Herculex I | $n = 100$ | 0.04 ± 0.26 c |
| | YieldGard CB | $n = 20$ | 5.00 ± 0.57 a |
| | Check | $n = 60$ | 3.29 ± 0.33 b |

[1] Herculex I and Herculex Xtra ratings combined.

[2] Means at the same location and followed by the same letter are not statistically significant by ANOVA, $P = 0.05$.

**TABLE 6 • Composite performance of all Herculex[1] and YieldGard Corn Borer hybrids at three Iowa locations, 2006.**

| Trait | Ears examined | Mean cm damage/ear[2] |
|---|---|---|
| Herculex I | $n = 240$ | 0.22 ± 0.19 b |
| YieldGard CB | $n = 240$ | 3.42 ± 0.19 a |
| Check | $n = 180$ | 3.51 ± 0.22 a |

[1] Herculex I and Herculex Xtra ratings combined.

[2] Means followed by the same letter are not statistically significant by ANOVA, $P = 0.05$.


cutworm moth flights. M.S. thesis, University of Nebraska. 47 pp.

Appel, L.L., R.J. Wright, and J.B. Campbell. 1993. Economic injury levels for western bean cutworm, *Loxagrotis albicosta* (Smith) (Lepidoptera: Noctuidae), eggs and larvae in field corn. *Journal of the Kansas Entomological Society* 66:434–438.

Blickenstaff, C.C. 1979. *History and Biology of the Western Bean Cutworm in Southern Idaho, 1942–1977.* University of Idaho Agricultural Experiment Station Bulletin 592. 23 pp.

Dorhout, D.L., and M.E. Rice. 2004. First report of western bean cutworm, *Richia albicosta* (Noctuidae), in Illinois and Missouri. *Crop Management* (http://www.plantmanagementnetwork.org/pub/cm/brief/2004/cutworm).

Gray, M.E. 2000. Special report: New soybean insect pest discovered in northern Illinois, Wisconsin, and Michigan. *Pest Management and Crop Development Bulletin*, No. 20. University of Illinois Extension, Champaign-Urbana. (http://www.ipm.uiuc.edu/bulletin/pastpest/articles/200020h.html).

Hagen, A.F. 1962. The biology and control of the western bean cutworm in dent corn in Nebraska. *Journal of Economic Entomology* 55:628–631.

Hagen, A.F. 1963. Evaluation of populations and control of the western bean cutworm in field beans in Nebraska. *Journal of Economic Entomology* 56:222–224.

Iowa State University. 2006. *Western Bean Cutworm Monitoring Network* (http://www.ent.iastate.edu/trap/westernbeancutworm/isite).

Mason, C.E., M.E. Rice, D.D. Calvin, J.W. Van Duyn, W.B. Showers, W.D. Hutchison, J.F. Witkowski, R.A. Higgins, D.W. Onstad, and G.P. Dively. 1996. *European Corn Borer Ecology and Management.* North Central Regional Extension, Publication No. 327, Iowa State University.

Metcalf, R.L. 1983. Implications and prognosis of resistance to insecticides, pp. 703–733. In Georghiou, G.P., and T. Saito (eds). *Pest Resistance to Pesticides.* Plenum Press, New York.

O'Rourke, P.K., and W.D. Hutchison. 2000. First report of the western bean cutworm, *Richia albicosta* (Smith) (Lepidoptera: Noctuidae), in Minnesota corn. *Journal of Agricultural and Urban Entomology* 17:213–217.

Pedigo, L. P., and M. E. Rice. 2006. Entomology and Pest Management, 5th edition. Pearson Prentice Hall. Upper Saddle River, NJ.

Rice, M.E. 2000. *Western Bean Cutworm Hits Northwest Iowa.* Integrated Crop Management IC-484 (22:163). Iowa State University Extension, Ames, IA (http://www.ipm.iastate.edu/ipm/icm/2000/9-18-2000/wbcw.html).

Seymour, R.C., G.L. Hein, R.J. Wright, and J.B. Campbell. 2004. *Western Bean Cutworm in Corn and Dry Beans.* University of Nebraska (http://www.ianrpubs.unl.edu/sendIt/g1359.pdf).

Steffey, K.L., M.E. Rice, J. All, D.A. Andow, M.E. Gray, and J.W. Van Duyn (eds). 1999. *Handbook of Corn Insects.* Entomological Society of America, Lanham, MD.

# Transgenic Corn Rootworm Hybrids: Assessing Performance in a Variant Western Corn Rootworm Arena

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The 2006 growing season proved to be another challenging year for producers throughout Illinois as they attempted to limit yield losses in their cornfields due to impressive root pruning and silk clipping activities by western corn rootworms. Yield loss attributed to corn rootworm damage is generally most extreme in drought years. Precipitation across our three test sites (DeKalb, Monmouth, and Urbana) was most generous in Urbana and least abundant in Monmouth, particularly for the month of July (Table 1). In Urbana, the rainfall total for July was nearly 8 inches; whereas in Monmouth, fewer than 2 inches of precipitation accumulated for the month. These extremes in rainfall totals enable us to assess the protection performance of various corn rootworm products across a broader range of environmental conditions.

**Table 1 • Precipitation totals (inches) for DeKalb, Monmouth, and Urbana, from April through August 2006.**

| Months | DeKalb | Monmouth | Urbana |
|---|---|---|---|
| April | 3.55 | 3.21 | 4.41 |
| May | 4.01 | 1.47 | 3.06 |
| June | 3.19 | 2.38 | 1.65 |
| July | 2.45 | 1.65 | 7.85 |
| August | 2.30 | 3.67 | 3.0 |
| TOTALS | 15.5 | 12.38 | 19.97 |

The discussion and information contained within this paper focus on root rating data and do not describe yield results. Accurately predicting corn yield with root rating data has never been very successful due to the tangle of interactions among corn hybrids with respect to root regeneration characteristics, level of root injury, and environmental conditions, particularly precipitation patterns (Gray and Steffey 1998). In addition, comparing yields across treatments has become a bit more complicated by the inclusion of more Bt corn rootworm hybrids (multiple events) and their corresponding isolines in our efficacy experiments. Although we used a trap crop system (late-planted corn in 2005 interplanted with pumpkins) to ensure greater rootworm injury in our test plots, we witnessed extreme root injury even by our trap crop standards. By using this approach, we intentionally place corn rootworm products under greater scrutiny.

Although it is less common to witness root pruning as great as occurred in our experiments, severe root injury and lodging do occur in some producers' fields each year. We believe the results from our trials enable producers to make more informed choices regarding product selection for corn rootworms. The root rating results for three of our corn rootworm product efficacy experiments (DeKalb, Monmouth, and Urbana) are presented in Table 2. Mean root injury values are not presented for the Perry location due to very low corn rootworm pressure at this site, including the untreated check. Despite the low corn rootworm injury at Perry in 2006, we intend to continue our efficacy experiments in western Illinois. This is primarily in response to the variant western corn rootworm's expanding range.

**TABLE 2 • Root ratings[1] and percentage consistency[1] for corn rootworm products, DeKalb, Monmouth, and Urbana, University of Illinois, 2006.**

| Products | Rate[2,3] | Placement | DeKalb[4] Root Rating[7] | DeKalb[4] Percentage Consistency | Monmouth[5] Root Rating[7] | Monmouth[5] Percentage Consistency | Urbana[6] Root Rating[7] | Urbana[6] Percentage Consistency |
|---|---|---|---|---|---|---|---|---|
| Aztec 2.1G | 6.7 oz | Band | 0.58 gh | 85% | 0.23 fg | 100% | 0.68 fgh | 70% |
| Aztec 2.1G + Poncho 250[2] | 6.7 oz | Band | 0.96 efg | 60% | 0.20 fg | 100% | 0.53 gh | 90% |
| Aztec 2.1G + Poncho 1250[9] | 6.7 oz | Band | 0.52 gh | 80% | 0.17 fg | 100% | 0.57 gh | 95% |
| Aztec 4.67G | 3 oz | Smart Box–Furrow | 0.54 gh | 80% | 0.20 fg | 100% | 0.65 gh | 80% |
| Capture LFR 1.5EC | 8.5 fl oz/A | Furrow | 1.6 a-d | 23% | — | — | — | — |
| Force 3G | 4 oz | Band | 0.55 gh | 85% | 0.57 d | 80% | 1.01 e | 50% |
| Fortress 5G | 4 oz | Smart Box–Furrow | 0.73 fgh | 65% | 0.38 d-g | 100% | 0.55 gh | 85% |
| Fortress 2.5G | 8 oz | Furrow | 1.28 def | 30% | 0.39 def | 90% | 0.54 gh | 95% |
| Lorsban 15G | 8 oz | Band | 0.80 fgh | 65% | 0.47 de | 95% | 0.63 gh | 75% |
| Poncho 1250[9] | 1.25 mg a.i./seed | Seed treatment | 1.24 cde | 5% | 1.65 b | 15% | 1.97 cd | 0% |
| HxXTRA + Poncho 250[8] (Pioneer 34A18) | — | Transgenic | 0.08 i | 95% | 0.24 g | 95% | 0.47 h | 85% |
| Untreated Pioneer Check (34A16) + Poncho 250[8] | — | — | 2.01 ab | 0% | 2.56 a | 0% | 2.43 abc | 0% |
| HxRW + Cruiser[10] (Mycogen 2G777) | — | Transgenic | — | — | 0.22 fg | 95% | 0.55 gh | 85% |
| HxXTRA + Cruiser[10] (Mycogen 2P788) | — | Transgenic | — | — | 0.40 efg | 80% | 0.44 h | 90% |
| Untreated Mycogen 2784 Check | — | — | — | — | 2.90 a | 0% | 2.94 a | 0% |
| YGRW (DeKalb 61-68) + Poncho 250[8] | — | Transgenic | 0.49 h | 75% | 0.39 d-g | 85% | 0.96 ef | 35% |
| Untreated DeKalb Check (DK61-72) | — | — | 2.07 ab | 0% | 2.98 a | 0% | 2.95 a | 0% |

Footnotes continued on next page

[1] Root ratings are based on the 0 to 3 root-rating scale developed by Oleson et al. (2005): 0.00 = no feeding damage; 1.0 = one node (circle of roots), or the equivalent of an entire node, pruned back to within approximately 3.8 cm (1.5 inches) of the stalk (or soil line if roots originate above ground nodes); 2.0 = two complete nodes pruned; 3.0 = three or more complete nodes pruned (highest rating that can be given). Percentage consistency is the percentage of roots with a node injury rating < 1.0. Five randomly selected root systems were dug from the second or third row of each four-row plot, in each of four replicates.

[2] Rates of application for band and in-furrow placements are ounces per 1,000 feet of row.

[3] Rates of application for seed treatments are milligrams of active ingredient per seed.

[4] Planting date April 27, 2006, into a trap crop (late-planted corn interplanted with pumpkins); root evaluation date July 25, 2006; DeKalb 61-72 was the hybrid used for all soil insecticide treatments.

[5] Planting date May 4, 2006, into a trap crop (late-planted corn interplanted with pumpkins); root evaluation date July 24, 2006; DeKalb 61-72 was the hybrid used for all soil insecticide treatments.

[6] Planting date April 28, 2006, into a trap crop (late-planted corn interplanted with pumpkins); root evaluation date July 17, 2006; DeKalb 61-72 was the hybrid used for all soil insecticide treatments. Mycogen treatments were planted May 6, 2006.

[7] Means followed by the same letter (within a column) do not differ significantly ($P = 0.05$, Duncan's New Multiple Range Test).

[8] Poncho applied at 0.25 mg a.i./seed.

[9] Poncho applied at 1.25 mg a.i./seed.

[10] Cruiser applied at 0.25 mg a.i./seed.

## Corn Rootworm Product Performance Results—July Evaluations

The level of root injury in the untreated check (DK 61-72) was 2.07, 2.98, and 2.95 in our plots at DeKalb (July 25), Monmouth (July 24), and Urbana (July 17), respectively. These levels of root injury are extreme, particularly at Monmouth and Urbana (three nodes of roots destroyed). For all soil insecticide treatments, DK 61-72 was the hybrid chosen for our experiments at each study site. The performance of Aztec was excellent at Monmouth (driest location), with very low root injury and 100% consistency (100% of roots had injury < 1.0) across four treatments. However, in DeKalb and Urbana, root pruning in the Aztec treatments was typically ½ node or greater. The consistency of root protection also was reduced in DeKalb and Urbana, ranging from 60% to 95%. The addition of Poncho 250 or 1250 with Aztec 2.1G did not enhance the level of root protection against corn rootworms. The results from our trials, again, are very clear with respect to this point. The addition of this insecticidal seed treatment with Aztec 2.1G is not a good investment and most likely hastens the potential development of resistance to the neonicotinoid seed treatments. The performance of Poncho 1250 as a stand-alone corn rootworm treatment was very poor, with root ratings of 1.24, 1.65, and 1.97 and consistency ratings of 5%, 15%, and 0% for DeKalb, Monmouth, and Urbana, respectively. Producers who continue to use this product to protect their refuge may be in for some unpleasant surprises. For several years, the insecticidal seed treatments have not provided consistent corn rootworm protection in our trials.

Performance of the other granular soil insecticides varied across locations. Root ratings in the Force 3G treatment averaged approximately ½ node of roots pruned in DeKalb and Monmouth; however, in Urbana, more than one node of roots was destroyed by July 17, with 50% of the roots exceeding a root rating of 1.0. This is much greater root injury than we have typically encountered in our experimental trials with Force. Root protection for both formulations of Fortress was poorest at the DeKalb location, with ¾ of a node and 1¼ nodes of roots destroyed in the 5G and 2.5G formulations, respectively. The root protection of Fortress was much better in Monmouth and Urbana, with root ratings ranging from 0.39 to 0.63. Interestingly, another organophosphate insecticide treatment, Lorsban 15G, had the most root injury (0.80, nearly one node destroyed) at the DeKalb location. Root protection with Lorsban at Monmouth and Urbana was better, with root ratings of 0.47 and 0.63, respectively. Unlike most other granular soil insecticides that offer more consistent root protection when applied in a band, Fortress generally provides more consistent root protection when placed in-furrow, as in our experiments.

Although many producers would like the flexibility to use a liquid insecticide for their corn rootworm control program, we have not witnessed consistent root protection from liquid formulations of soil insecticides. An in-furrow application of Capture LFR (1.5 EC) offered poor root protection by mid-July (1½ nodes destroyed) at the DeKalb location. This treatment was not applied in Monmouth or Urbana.

In 2006, for the first time, we were able to compare in the same trials the root protection afforded by transgenic corn rootworm hybrids with different events from Monsanto (MON 863, Cry3Bb1, YGRW), Pioneer Hi-Bred International, Incorporated (DAS-59122-7, Cry34Ab1/Cry35Ab1, HxXTRA), and Mycogen (DAS-59122-7, Cry34Ab1/Cry35Ab1, HxRW, HxXTRA). In general, the root protection of these transgenic corn

rootworm hybrids was very good to excellent. The HxXTRA (Pioneer 34A18) treatment had July root ratings of 0.08, 0.24, and 0.47 in DeKalb, Monmouth, and Urbana, respectively. Considering the level of root injury in the control, these are very acceptable levels of root protection. For this treatment (HxXTRA, Pioneer 34A18), root injury comparisons should be made with the appropriate control, Pioneer 34A16, which was also treated with Poncho 250. The HxRW (Mycogen 2G777) and HxXTRA (Mycogen 2P788) transgenic corn rootworm treatments provided very good (½ node or less pruned) root protection at the Monmouth (root ratings: HxRW, 0.22; HxXTRA, 0.40) and Urbana (HxRW, 0.55; HxXTRA, 0.44) locations. These root ratings should be compared with the appropriate control (Mycogen 2784), which did not receive any insecticidal seed treatment. Due to late shipments of seed, the Mycogen Bt corn rootworm treatments were not planted until May 6 at the Urbana site. This is certainly much later than desired, and we should expect better root protection when planting is delayed to this extent. The YieldGard RW (DK 61-68) treatment had root ratings in July of 0.49, 0.39, and 0.96 at the DeKalb, Monmouth, and Urbana experiments, respectively. These root ratings should be compared with the untreated check (DK 61-72), which did not receive any insecticidal seed treatment. The level of root injury (nearly one node pruned) in Urbana was much greater than anticipated for mid-July. In addition, the planting date for this treatment was April 28, much later than most producers hope to achieve in east central Illinois. How severe would the root injury have been if planting had occurred during the first week of April?

## Corn Rootworm Product Performance Results—August Evaluations

During the past several years, we have observed late-season brace root pruning on some YieldGard RW hybrids, especially at the Urbana location (Gray et al. 2005, 2006). To a lesser extent, late-season brace root pruning also has been observed with some YieldGard RW hybrids at the DeKalb site. At Monmouth, this phenomenon has not occurred. We have speculated previously that the variant western corn rootworm may be at least partially responsible for these observations. Densities of the variant western corn rootworm are greater in Urbana and at intermediate levels in DeKalb, and numbers are increasing near Monmouth. Variant western corn rootworms may be more aggressive root feeders and less susceptible to the Bt protein expressed by YieldGard RW hybrids. There is some circumstantial evidence in the entomological literature (Siegfried et al. 2005) to support our hypothesis. Field observations during the past few years also provide some additional circumstantial evidence to support our idea. More work is clearly warranted to explore this hypothesis more fully.

As in previous years, the YieldGard RW hybrid (DK 61-68 + Poncho 250) at the Urbana experimental site experienced an increase in rootworm pruning from mid-July (0.96) to early August (1.46). By mid-July, nearly one full node of roots was pruned on the YieldGard RW treatment; by early August, approximately 1-½ nodes of roots were destroyed (Table 3). By August 8, the YieldGard RW treatment in Urbana had a consistency percentage of 0%. This is not an acceptable level of root protection. Plants are much more susceptible to lodging when one full node of roots has been pruned. Excessive lodging can lead to more significant physiological yield losses and can increase harvest difficulties. The root protection of the YieldGard RW treatment at DeKalb and Monmouth was much better, with August root ratings of 0.41 and 0.59, respectively. The consistency percentages in August for the YieldGard RW and HxXTRA (Pioneer 34A18 + Poncho 250) treatments were identical at DeKalb and Monmouth, 100% and 80%. Why was the performance of the YieldGard RW treatment so compromised in Urbana as compared with the other two locations? The August level of root injury in the untreated check (DK 61-72) was similar in Monmouth (2.82) and Urbana (3.0). So, variation in corn rootworm pressure doesn't appear to be a satisfactory explanation. The Aztec 2.1G treatment provided fair (DeKalb, 0.58 to 0.78; Urbana, 0.68 to 0.63) to very good (Monmouth, 0.23 to 0.41) protection of roots at both root rating dates across all three locations. The root protection offered by Poncho 1250 was very poor by August 8 for DeKalb, Monmouth, and Urbana, at 1.42, 1.72, and 2.35, respectively.

## Evaluation of YieldGard Rootworm Transgenic Hybrids in Monmouth and Urbana

In 2005, we evaluated eight YieldGard RW hybrids (MON 863) in a trial located near Urbana. We concluded that some variation in root protection was present among the transgenic hybrids we evaluated. In 2006, we expanded the trial to include ten YieldGard RW hybrids (MON 863) and planted them in two locations, Monmouth and Urbana (Tables 4 and 5). In each year of this study, we

**TABLE 3 • Root injury ratings[1] and percentage consistency[1] for first and second evaluations: DeKalb, Monmouth, and Urbana, University of Illinois, 2006.**

| Products | Rate[2] | Placement | DeKalb[3] July 25 | DeKalb[3] August 8 | DeKalb[3] August 8 % Consistency | Monmouth[4] July 24 | Monmouth[4] August 8 | Monmouth[4] August 8 % Consistency | Urbana[5] July 17 | Urbana[5] August 8 | Urbana[5] August 8 % Consistency |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Aztec 2.1G | 6.7 oz | Band | 0.58 gh | 0.78 c | 69% | 0.23 fg | 0.41 c | 95% | 0.68 fgh | 0.63 d | 80% |
| Poncho 1250[6] a.i./seed | 1.25 mg | Seed treatment | 1.24 cde | 1.42 b | 15% | 1.65 b | 1.72 b | 5% | 1.97 cd | 2.35 b | 0% |
| HxXTRA + Poncho 250[7] (Pioneer 34A18) | — | Transgenic | 0.08 i | 0.19 d | 100% | 0.24 g | 0.52 c | 80% | 0.47 h | 0.37 d | 95% |
| YGRW (DK 61-68) + Poncho 250[7] | — | Transgenic | 0.49 h | 0.41 d | 100% | 0.39 d-g | 0.59 c | 80% | 0.96 ef | 1.46 c | 0% |
| Untreated DeKalb Check (DK61-72) | — | — | 2.07 ab | 2.15 a | 0% | 2.98 a | 2.82 a | 0% | 2.95 a | 3.0 a | 0% |

[1] Root ratings are based on the 0 to 3 root-rating scale developed by Oleson et al. (2005): 0.00 = no feeding damage; 1.0 = one node (circle of roots), or the equivalent of an entire node, pruned back to within approximately 3.8 cm (1.5 inches) of the stalk (or soil line if roots originate above ground nodes); 2.0 = two complete nodes pruned; 3.0 = three or more complete nodes pruned (highest rating that can be given). Percentage consistency is the percentage of roots with a node injury rating < 1.0. Five randomly selected root systems were dug from the second or third row of each four-row plot, in each of four replicates. Means followed by the same letter (within a column) do not differ significantly ($P = 0.05$, Duncan's New Multiple Range Test).

[2] Rates of application for band and in-furrow placements are ounces per 1,000 feet of row. Rates of application for seed treatments are milligrams of active ingredient per seed.

[3] Planting date April 27, 2006, into a trap crop (late-planted corn interplanted with pumpkins). DK 61-72 was the hybrid used for all soil insecticide treatments. First root rating evaluation was July 25; second evaluation was August 8.

[4] Planting date May 4, 2006, into a trap crop (late-planted corn interplanted with pumpkins). DK 61-72 was the hybrid used for all soil insecticide treatments. First root rating evaluation was July 24; second evaluation was August 8.

[5] Planting date April 28, 2006, into a trap crop (late-planted corn interplanted with pumpkins). DK 61-72 was the hybrid used for all soil insecticide treatments. First root rating evaluation was July 17; second evaluation was August 8.

[6] Poncho applied at 1.25 mg a.i./seed.

[7] Poncho applied at 0.25 mg a.i./seed.

also planted a check hybrid (non-Bt). In addition, in each year, two transgenic YieldGard RW hybrids that failed to meet Monsanto's commercialization standards were included in our experiments. The genetic background and commercial names of all hybrids remain unknown to us for both years, and treatments are simply labeled with letters of the alphabet, A through K, for the 2006 experiment. For the 2006 experiment, hybrid B served as the control (nontransgenic hybrid), and hybrids D and F (both YieldGard RW hybrids, MON 863) failed to meet commercialization standards (Monsanto protocols). Why did we establish a duplicate experiment near Monmouth? To gather more data regarding our hypothesis concerning the variant western corn rootworm's ability to inflict more root injury on YieldGard RW hybrids in the Urbana area, we planted another trial with the same hybrids near Monmouth, an area that does not support high densities of variant western corn rootworms, yet.

Root protection at the Monmouth site (Table 4) was excellent across the YieldGard RW hybrids as of July 24, with typical root injury of ¼ node pruned or less. This protection occurred despite heavy pressure, as evidenced by the severity of root pruning (2.63) in the check (non-Bt hybrid). By the third week in July, root injury ranged from 0.06 (hybrid C, 100% consistent) to 0.30 (hybrid K, 98% consistent) among those YieldGard RW hybrids that were commercialized. By August 8, root protection across most commercial YieldGard RW hybrids ranged from ⅓ to ½ node of roots pruned. The range in root injury was 0.22 (hybrid C, 98% consistent) to 0.75 (hybrid K, 65% consistent). The two YieldGard RW hybrids that were not commercialized, D and F, had root ratings of 1.09 and 1.44, respectively, by August 8. Overall, we conclude that most commercialized YieldGard RW hybrids offered very good to excellent root protection at the Monmouth site. However, by August 8, hybrid K had ¾ of a node of roots pruned and a consistency percentage of only 65%. This level of protection is less than desirable. All hybrids were planted at the Monmouth site on May 4, 2006. Many farmers consider this planting date late by modern corn production standards. If these YieldGard RW hybrids were planted in early to mid-April, would the root ratings have been affected? We intend to examine this question more critically with the initiation of planting-dates studies in 2007.

The YieldGard RW hybrid evaluation trial located near Urbana (Table 5) was planted on May 5, 2006. On July 20, root injury across the commercialized YieldGard RW hybrids typically ranged from ¼ to ⅓ node of roots pruned. Root injury in the non-Bt check (hybrid B) was

**TABLE 4 • Root ratings[1,2] and percentage consistency[1] for YieldGard (MON 863) corn rootworm hybrids (A–K) evaluation trial, University of Illinois, Monmouth[3], 2006.**

| Root Evaluation Dates | A | B | C | D | E | F | G | H | I | J | K |
|---|---|---|---|---|---|---|---|---|---|---|---|
| July 24 Ratings[4] | 0.19 de | 2.63 a | 0.06 e | 0.76 c | 0.20 de | 1.00 b | 0.16 de | 0.22 de | 0.11 de | 0.15 de | 0.30 d |
| July 24 % Consistency | 100% | 0% | 100% | 53% | 90% | 35% | 95% | 88% | 100% | 95% | 98% |
| August 8 Ratings[4] | 0.34 e | 2.74 a | 0.22 e | 1.09 c | 0.42 e | 1.44 b | 0.38 e | 0.41 e | 0.23 e | 0.45 e | 0.75 d |
| August 8 % Consistency | 93% | 0% | 98% | 41% | 90% | 18% | 90% | 82% | 98% | 83% | 65% |

[1] Root ratings are based on the 0 to 3 root-rating scale developed by Oleson et al. (2005): 0.00 = no feeding damage; 1.0 = one node (circle of roots), or the equivalent of an entire node, pruned back to within approximately 3.8 cm (1.5 inches) of the stalk (or soil line if roots originate above ground nodes); 2.0 = two complete nodes pruned; 3.0 = three or more complete nodes pruned (highest rating that can be given). Percentage consistency is the percentage of roots with a node injury rating < 1.0.

[2] Means followed by the same letter do not significantly differ within a row ($P = 0.05$, Duncan's New Multiple Range Test).

[3] All YieldGard Rootworm hybrids (MON 863) were planted on May 4, 2006.

[4] Ten randomly selected root systems were dug from the center two rows of each four-row plot (in each of four replicates) and washed and evaluated for corn rootworm larval injury.

**TABLE 5 • Root ratings[1,2] and percentage consistency[1] for YieldGard (MON 863) corn rootworm hybrids (A–K) evaluation trial, University of Illinois, Urbana[3], 2006.**

| Root Evaluation Dates | A | B | C | D | E | F | G | H | I | J | K |
|---|---|---|---|---|---|---|---|---|---|---|---|
| July 20 Ratings[4] | 0.39 d | 2.52 a | 0.24 d | 0.79 c | 0.29 d | 1.21 b | 0.34 d | 0.36 d | 0.41 d | 0.14 d | 0.36 d |
| July 20 % Consistency | 88% | 0% | 95% | 48% | 93% | 10% | 95% | 88% | 87% | 100% | 90% |
| August 7 Ratings[4] | 0.86 c | 2.68 a | 0.62 d | 1.50 b | 0.89 c | 1.92 b | 0.83 c | 0.83 c | 0.79 c | 0.66 c | 0.91 c |
| August 7 % Consistency | 54% | 0% | 83% | 10% | 58% | 0% | 63% | 65% | 60% | 75% | 55% |

[1] Root ratings are based on the 0 to 3 root-rating scale developed by Oleson et al. (2005): 0.00 = no feeding damage; 1.0 = one node (circle of roots), or the equivalent of an entire node, pruned back to within approximately 3.8 cm (1.5 inches) of the stalk (or soil line if roots originate above ground nodes); 2.0 = two complete nodes pruned; 3.0 = three or more complete nodes pruned (highest rating that can be given). Percentage consistency is the percentage of roots with a node injury rating < 1.0.

[2] Means followed by the same letter do not significantly differ within a row ($P = 0.05$, Duncan's New Multiple Range Test).

[3] All YieldGard Rootworm hybrids (MON 863) were planted on May 5, 2006.

[4] Ten randomly selected root systems were dug from the center two rows of each four-row plot (in each of four replicates) and washed and evaluated for corn rootworm larval injury.

2.52 (2½ nodes of roots pruned) on July 20. This level of root injury is similar to that observed in the Monmouth YieldGard RW hybrid trial. The range in root injury among commercialized hybrids was 0.14 (hybrid J, 100% consistent) to 0.41 (hybrid I, 87% consistent) on July 20. Considering the level of injury in the control, this protection is quite good. By August 7, 2½ weeks after the first root evaluations, the level of root injury increased by approximately ½ node of roots pruned across the YieldGard RW hybrids. The range in injury across the commercialized hybrids was 0.62 (hybrid C, 83% consistent) to 0.91 (hybrid K, 55% consistent). These two YieldGard RW hybrids are the same two that displayed this range at the Monmouth site. As of August 7, the two YieldGard RW hybrids that were not commercialized, D and F, had root injury ratings of 1.50 and 1.92, respectively.

Did the overall root protection YieldGard RW hybrids diminish at the Urbana location as compared with the Monmouth site? An examination of the percentage consistency (percentage of roots with a node injury rating < 1.0) of the various hybrid treatments may help to answer this question. The percentage consistency of every YieldGard RW hybrid (commercialized and noncommercialized) was lower in the Urbana experiment as compared with Monmouth by the second root evaluations (August 7 and 8). The reductions in percentage consistency between these two experiments for the various hybrids were as follows: hybrid A, 39%; hybrid C, 15%; hybrid D, 31%; hybrid E, 32%; hybrid F, 18%; hybrid G, 27%; hybrid H, 17%; hybrid I, 38%; hybrid J, 8%; and hybrid K, 10%. These data would appear to support our hypothesis that the variant western corn rootworm may be more injurious than nonvariant populations to some YieldGard RW hybrids. As indicated previously, the variant western corn rootworm appears entrenched in east central Illinois. Further investigations are needed to confirm this hypothesis. Eventually, it will be necessary to separate variant from nonvariant western corn rootworms, then subject transgenic corn rootworm hybrids to precise infestation levels of both populations and evaluate root injury and adult emergence across the treatments. This past year, researchers took a step forward in being able to separate variant and nonvariant western corn rootworm populations.

In the August 2006 issue of *Environmental Entomology*, Lisa Knolhoff (graduate student in the Department of Entomology, University of Illinois at Urbana-Champaign) and David Onstad, Joe Spencer, and Eli Levine (entomologists with the University of Illinois at Urbana-

Champaign and Illinois Natural History Survey) reported how they could separate variant from nonvariant western corn rootworms using a behavioral bioassay. As the authors indicated in their paper, this is the "first step in determining the genetic basis of rotation resistance" (Knolhoff et al. 2006).

By measuring the time it took for western corn rootworm adults to exit behavioral assay arenas, the investigators began to observe some interesting differences among beetles that had been collected from different areas (Monmouth, Perry, Urbana, Illinois; and Ames, Iowa). The arenas were cylindrical and made of plastic mesh screen with an opening in an inverted cone at the top. The authors made the following observation: "Results from these assays indicate that *D. v. virgifera* females from regions where crop rotation is no longer effective are more active than females from regions where rotation remains effective." Differences among variant and nonvariant populations were more evident when the bioassay was performed in the field as compared with the laboratory. During 2004, beetles collected from Urbana were "consistently more active" than specimens obtained from Monmouth. Urbana is much nearer the geographic epicenter (Piper City, Ford County) of where it is believed the variant western corn rootworm had its origin. In 2005, western corn rootworm females collected near Ames, Iowa, were the "least active" as compared with the beetles collected from Urbana and Perry locations. These researchers concluded in the abstract of their paper: "Results were consistent with the hypothesis that a loss of fidelity to corn rather than any particular attractant is the cause of rotation resistance. Behavioral differences between populations of beetles in similar environments suggest that there is a genetic difference between rotation-resistant and wild-type *D. v. virgifera*, although no specific gene or genes have yet been identified."

In 2006, we conducted a very limited HxRW hybrid trial near Urbana (Table 6) to determine whether root protection declined from mid-July to early August. Two HxRW hybrids were provided by Dow AgroSciences and two were provided by Pioneer Hi-Bred International, Incorporated. The identities of these transgenic corn rootworm hybrids remain unknown to us. Although this trial was much more limited in scope than the hybrid experiments described previously for YieldGard RW hybrids, it is a start in evaluating the effectiveness of HxRW hybrids at early (July) and later root evaluation dates (August). The small set of HxRW hybrids that we evaluated offered excellent root protection as of July 19 (Table 6). By August 7, the level of root protection remained excellent for the HxRW hybrids; only the Dow B hybrid (0.42 root rating) exhibited a moderate level of pruning. We hope to expand the number of HxRW hybrids we evaluate and use more than one test site in the future.

**TABLE 6. Root ratings[1,2] and percentage consistency[1] for HxRW corn rootworm hybrids, University of Illinois, Urbana[3], 2006.**

| Hybrid | Root Rating[4] July 19 | Percentage Consistency | Root Rating August 7 | Percentage Consistency |
|---|---|---|---|---|
| Dow A | 0.09 cd | 100% | 0.18 bc | 100% |
| Dow B | 0.17 c | 100% | 0.42 b | 88% |
| Dow C (UTC) | 2.90 a | 0% | 2.94 a | 0% |
| Pioneer A | 0.06 d | 100% | 0.18 bc | 100% |
| Pioneer B | 0.07 d | 100% | 0.14 c | 100% |
| Pioneer C (UTC) | 2.58 b | 4% | 2.90 a | 0% |

[1] Root ratings are based on the 0 to 3 root-rating scale developed by Oleson et al. (2005): 0.00 = no feeding damage; 1.0 = one node (circle of roots), or the equivalent of an entire node, pruned back to within approximately 3.8 cm (1.5 inches) of the stalk (or soil line if roots originate above ground nodes); 2.0 = two complete nodes pruned; 3.0 = three or more complete nodes pruned (highest rating that can be given). Percentage consistency is the percentage of roots with a node injury rating < 1.0.

[2] Means followed by the same letter do not significantly differ within a column ($P = 0.05$, Duncan's New Multiple Range Test).

[3] All Herculex RW hybrids were planted on May 23, 2006, in a field that had been a trap crop (late-planted corn and pumpkins preceding year) near Urbana.

[4] Six randomly selected root systems were dug from the center two rows of each four-row plot (in each of four replicates) on July 19 and August 7, 2006.

## Concluding Remarks

In 2005, Bt hybrids were planted on 35% of the U.S. corn acreage (Fernandez-Cornejo and Caswell 2006). The majority of these transgenic Bt corn hybrids were aimed at the European corn borer. In 2003, Bt hybrids (MON 863, Cry3Bb1, YieldGard RW) targeted at corn rootworms were commercialized for the first time. In 2006, HxRW hybrids (DAS-59122-7, Cry34Ab1/Cry35Ab1) were commercialized for the first time. These transgenic corn hybrids also are designed to provide root protection against corn rootworm larvae. In 2007, Syngenta intends to commercialize a new transgenic corn rootworm event (MIR604, mCry3A, Agrisure RW). The number of transgenic corn rootworm (Bt) hybrids available to producers continues to expand. The number of transgenic corn acres, especially those acres devoted to stacked hybrids (combinations of Bt events and herbicide tolerance traits) is expected to increase quite significantly over the next several years. It is imperative that research on the efficacy of these transgenic corn rootworm hybrids be continued by land grant scientists in multiple locations across the Corn Belt. As we have demonstrated, in this technology's infancy, not all transgenic corn rootworm hybrids (even those with the same event) offer the same level of root protection against corn rootworms. Producers should be equipped with as much information as possible in order to make the most informed pest management decisions. As the number of Bt acres increases, so, too, will the selection pressure for resistance development by multiple insect pests of corn. This fact underscores the importance of strict adherence to resistance management protocols that have been developed for these impressive pest management tools.

## References


Fernandez-Cornejo, J., and M. Caswell. 2006. *The First Decade of Genetically Engineered Crops in the United States*. USDA Economic Research Service, Economic Information Bulletin, Number 11, Washington, DC.

Gray, M.E., and K.L. Steffey. 1998. Corn rootworm (Coleoptera: Chrysomelidae) larval injury and root compensation of 12 maize hybrids: An assessment of the economic injury index. *Journal of Economic Entomology* 91:723–740.

Gray, M.E., and K.L. Steffey. 2005. Transgenic YieldGard rootworm hybrid stumbles in Urbana experiment: Why? pp. 41–46. In Proceedings of the 2005 Illinois Crop Protection Technology Conference, University Illinois Extension, Urbana-Champaign.

Gray, M.E., K.L. Steffey, R. Estes, J.B. Schroeder, and D.M. Bakken. 2006. Transgenic corn rootworm hybrids, soil insecticides, and seed treatments: Does anything work on the variant western corn rootworm? pp. 54–61. In Proceedings of the 2006 Illinois Crop Protection Technology Conference, University of Illinois Extension, Urbana-Champaign.

Knolhoff, L.M., D.W. Onstad, J.L. Spencer, and E. Levine. 2006. Behavioral differences between rotation-resistant and wild-type *Diabrotica virgifera virgifera* (Coleoptera: Chrysomelidae). *Environmental Entomology* 35(4):1049-1057.

Oleson, J.D., Y.K. Park, T.M. Nowatzki, and J.J. Tollefson. 2005. Node-injury scale to evaluate root injury by corn rootworms (Coleoptera: Chrysomelidae). *Journal of Economic Entomology* 98:1–8.

Siegfried, B.D., T.T. Vaughn, and T. Spencer. 2005. Baseline susceptibility of western corn rootworm (Coleoptera: Chrysomelidae) to Cry3Bb1 *Bacillus thuringiensis* toxin. *Journal of Economic Entomology* 98:1320–1324.

# Seed-Applied Insecticides, Soil Insecticides, and Bt Corn: Their Roles in Corn Production

*Kevin L. Steffey, Michael E. Gray, Jared B. Schroeder, and Ronald E. Estes*

By the simple act of planting corn seed, a corn grower now has expectations for controlling a large list of potential insect threats, both below and above ground, depending on the product selected—black cutworms, corn rootworms, European corn borers, southwestern corn borers, western bean cutworms, white grubs, and wireworms. Throw in the promise of protection against fall armyworms, flea beetles, grape colaspis, and seedcorn maggots, and a corn producer has what he or she has always hoped for—a simple, convenient, effective way to control the most economically important insect pests of corn. No handling of insecticides, less scouting, increased utilization of water and nutrients, increased yields, efficient weed control. What more can we ask for? The so-called triple stacks (Bt for corn rootworms, Bt for borers, the herbicide-resistant or -tolerant trait), with all seeds treated with a neonicotinoid insecticide (either Cruiser or Poncho), fulfill many pest management wishes.

If only we didn't have to concern ourselves with those annoying insect resistance management (IRM) requirements. And with triple stacks, IRM requirements are confusing.

Over the past several months, we have heard from numerous sources that some corn producers fully intend to disregard the insect resistance management recommendations by not planting a Bt corn refuge. The reasons why? It's inconvenient to handle soil insecticides for only 20% of the corn acres. The yields in non-Bt corn refuges are noticeably lower than the yields of transgenic Bt corn fields. Not-Bt corn refuge acres have to be scouted regularly. Controlling aboveground insects (e.g., European corn borer) is not efficient for only 20% of the corn.

All of the justifications for not planting non-Bt corn refuges seem to represent valid concerns, but the first bottom line is that the act of not planting a non-Bt corn refuge is an act of reneging on "binding contractual obligations on the grower to comply with the refuge requirements" (the grower agreement or stewardship agreement). This act is punishable by the registrant of the product associated with persistent noncompliance (e.g., denial of sales of Bt corn products). In addition, "seed dealers who are not fulfilling their obligations to inform/educate growers of their IRM obligations will lose their opportunity to sell [the transgenic Bt modified corn]." Finally, each registrant of Bt corn products must design and implement a comprehensive, ongoing IRM education program; design and implement an ongoing IRM compliance program; and establish and publicize a phased compliance approach. These requirements are included in all corn biopesticide registration action documents published by the United States Environmental Protection Agency (EPA).

The second and more long-term bottom line is that widespread disregard for IRM requirements for Bt corn will place significant selection pressure on a number of insect populations, including the ever-resilient western corn rootworm. The unfortunate end result of such selection pressure is that one or more pest insect populations will develop resistance to one or more active ingredients, creating the potential for widespread failures of insect control products and significant, possibly unprecedented,

yield losses. The potential economic ramifications of the development of insect populations resistant to insect control tactics (e.g., insecticides, crop rotation) are considerable. All of us involved in agriculture should know; we've been down that road before.

## The Future of Corn Insect Management Is All About Transgenic Hybrids—At Least for Now

All indications are that corn acres planted to transgenic hybrids will continue to increase. As seed companies escalate the rate of incorporation of Bt traits and herbicide resistance traits into their elite hybrids and as the yield benefits of these converted corn hybrids become more widely publicized, the growth in acreage of single-, double-, and triple-trait hybrids will be extraordinary. Fernando-Cornejo and Caswell (2006) offered the following statistics, among many others, regarding the recent growth of the Bt corn market: "Bt corn, originally developed to control the European corn borer, was planted on 35% of corn acreage in 2005, up from 24% in 2002. The recent increase in acreage share may be largely due to the commercial introduction in 2003/04 of a new Bt corn variety that is resistant to the corn rootworm, a pest that may be even more destructive to corn yield than the European corn borer." There is every reason to believe that, barring the development of a major problem with Bt corn, acreage of Bt corn will continue to increase at a dramatic pace.

The concerns driving the interest in planting Bt corn are noteworthy. The range of the variant western corn rootworm that lays eggs in soybeans, as well as in other crops, continues to spread. Many corn producers have experienced or observed the impact of a heavy infestation of corn rootworm larvae in corn planted after soybeans. It's also important to note that the western corn rootworm still lays eggs in cornfields, so the projected increase in corn-after-corn acres also will be a market for Bt corn products. The continuing establishment of western bean cutworms also has many corn producers on the alert and speculating when Bt corn will help them avert significant yield losses caused by this ear-infesting pest. An overview of the spreading distribution of the western bean cutworm is provided in another paper in these proceedings—Western Bean Cutworm and the Invasion of Illinois Corn: It's Like Déjà vu All Over Again.

And consider "old foes." For many years, populations of European corn borers seem to have been suppressed throughout most of Illinois and the rest of the Midwest. However, our annual survey for second-generation European corn borers in 2006 revealed a resurgence of European corn borers in some areas of the state, especially the central one-third (Table 1). The impact of Bt corn planted for control of corn borers was evident in some of the counties surveyed. For example, two of the authors surveyed ten fields in Morgan County in mid-September; fields with significant infestations of European corn borers were unmistakable from the road—broken tops, lodged stalks. In five of the ten fields surveyed, 90% or more of the stalks examined were infested with European corn borers (Figure 1). However, three of the ten fields surveyed had 0% infestation of European corn borers, and one of the fields had only 4% infestation. We assumed that these four fields had been planted to Bt corn for control of corn borers. Although European corn borers were few and far between in the Southwest and Southeast Crop Reporting Districts, there were indications of infestations by southwestern corn borers in many of the southern counties surveyed.

So, isn't Bt corn a good thing for corn producers, the environment, and society in general? For the most part, yes. Effective control of major insect pests of corn is a significant economic benefit for corn growers who produce continually higher yields. Bt corn is considered to be less environmentally disruptive than chemical insecticides, and effective host plant resistance is an integral part of an insect management program. In addition, the neonicotinoid insecticides applied to Bt corn seed also seem to have little impact on the environment. However, although some corn producers are tempted to plant Bt corn on all of their acres, the potential ecological impact of so

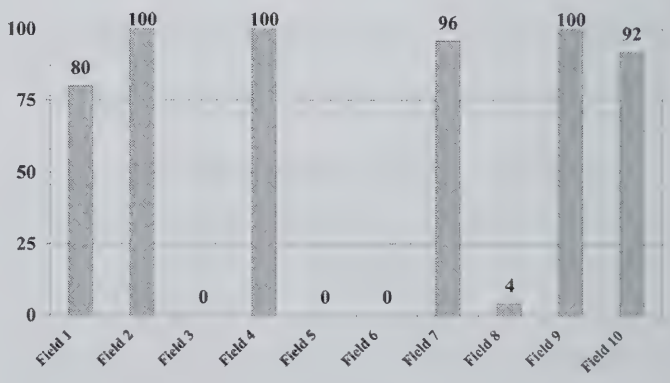


**FIGURE 1 • Percentage infestation of European corn borer larvae in ten randomly selected fields in Morgan County, Illinois, 2006.**

**TABLE 1 • Results from the 2006 survey for second-generation European corn borers, Illinois.**

| Counties[1] and Crop Reporting Districts | Percentage of plants infested, 2001 | European corn borer larvae per 100 plants |
|---|---|---|
| Bureau | 26 | 25.6 |
| Jo Daviess | 12 | 25.2 |
| Mercer | 9 | 23.0 |
| Ogle | 1 | 0.0 |
| Whiteside | 4 | 3.6 |
| Winnebago | 10 | 12.8 |
| Northwest | 10 | 15.03 |
| DeKalb | <1 | 0.4 |
| Kendall | 6 | 8.8 |
| LaSalle | 28 | 29.6 |
| McHenry | 17 | 19.8 |
| Will | 14 | 5.4 |
| Northeast | 13 | 12.8 |
| Adams | 81 | 131.8 |
| Fulton | 43 | 80.4 |
| Knox | 24 | 23.4 |
| McDonough | 15 | 30.4 |
| Schuyler | 35 | 63.2 |
| Warren | 34 | 113.4 |
| West | 39 | 73.77 |
| Logan | 25 | 48.8 |
| Macon | 32 | 25.4 |
| McLean | 21 | 34.2 |
| Peoria | 36 | 53.0 |
| Woodford | 42 | 59.8 |
| Central | 31 | 44.24 |
| Champaign | 22 | 8.0 |
| Iroquois | 10 | 10.2 |
| Livingston | 12 | 31.8 |
| Vermilion | 22 | 22.8 |
| East | 17 | 18.2 |
| Calhoun | 40 | 67.4 |
| Christian[2] | 35 | 28.8 |
| Greene | 63 | 104.0 |
| Madison | 44 | 99.2 |
| Montgomery | 50 | 105.0 |
| Morgan | 57 | 124.0 |
| Pike | 44 | 39.6 |
| Sangamon | 38 | 47.0 |
| West Southwest | 46 | 76.88 |
| Clark | 57 | 77.2 |
| Coles | 25 | 22.2 |
| Crawford | 31 | 40.2 |
| Effingham | 30 | 40.2 |
| Marion | 24 | 4.6 |
| Shelby[3] | 30 | 35.8 |
| East Southeast | 33 | 36.70 |
| Jackson | 0 | 0.0 |
| Monroe | 10 | 9.6 |
| Pulaski-Alexander | 0 | 0.0 |
| Washington | 20 | 21.8 |
| Southwest | 8 | 7.85 |
| Franklin | 2 | 0.0 |
| Massac | 0 | 0.0 |
| Saline | 16 | 10.4 |
| Wayne | 11 | 13.4 |
| White | 35 | 22.4 |
| Southeast | 13 | 9.24 |
| STATE | 33 | 23.24 |

[1] Unless otherwise indicated, 10 randomly selected fields were sampled in each county.
[2] 17 randomly selected fields were sampled.
[3] 11 randomly selected fields were sampled.

much Bt protein in agroecosystems could turn short-term economic gains into longer-term economic losses and environmental disruptions, which ultimately will affect all corn producers. There are legitimate ecological reasons for the requirements of IRM strategies, and we strongly encourage their deployment.

## What Types of Bt Corn Will Be Available in 2007?

Table 2 shows the types Bt corn products that will be available in 2007, with a list of insects controlled provided for each type of product. We have not listed the herbicide-resistant and herbicide-tolerant traits included in the triple stacks. The focus in this paper is insect management.

Bt corn products for control of European and southwestern corn borers (as well as for different levels of protection against other caterpillars) have been commercially available for several years, and corn producers in many areas have adopted their use. Bt corn products for control of rootworms were available for the first time in 2003 (YieldGard brands). Herculex brands for rootworm

control were sold and planted commercially for the first time in 2006. Agrisure RW corn hybrids will be sold commercially for the first time in 2007. YieldGard VT (Vector-Stack Transformation, VecTran) is the name of Monsanto's new, second-generation insect control technology. The Bt proteins in the YieldGard VT hybrids are the same proteins in other, equivalent YieldGard hybrids, but the method of transformation has been improved. YieldGard VT corn hybrids will be available on a limited basis in 2007.

How effective are these products for controlling corn rootworms? Efficacy data for YieldGard Rootworm, Herculex RW, and Herculex XTRA products are published in another paper in these proceedings—Transgenic Corn Rootworm Hybrids: Assessing Performance in a Variant Western Corn Rootworm Arena. Efficacy data for transgenic Bt products also have been published in articles in *the Bulletin*, http://www.ipm.uiuc.edu/bulletin. All of our efficacy data are published annually in *on Target*, our summary of field crop insect management trials (Department of Crop Sciences, University of Illinois at Urbana-Champaign, http://www.ipm.uiuc.edu/ontarget). Although all transgenic rootworm control products provide excellent control of corn rootworm larvae under most circumstances, there is evidence from both research trials and commercial fields of significant corn rootworm larval damage to these products. The reasons for these instances of greater-than-expected corn rootworm larval damage are speculative.

All Bt corn products have been and will be sold with IRM refuge requirements. Planting non-Bt corn refuges is required for all types of Bt corn, whether the Bt corn is intended for control of corn rootworms, European corn borers, or both, and whether the brand is YieldGard, Herculex, or Agrisure. The basic rule is 20% non-Bt corn refuge and 80% Bt corn, again regardless of target

**TABLE 2 • Transgenic Bt corn products for 2007[1]**

| Product | Insecticidal protein | Controls . . . |
|---|---|---|
| Agrisure CB | Cry 1Ab | European corn borer, southwestern corn borer (also offers suppression of corn earworm, fall armyworm) |
| Agrisure RW | mCry 3A | Western, northern, and Mexican corn rootworms |
| Agrisure CB/RW | Cry 1Ab + mCry 3A | European corn borer; southwestern corn borer; and western, northern, and Mexican corn rootworms (also offers suppression of corn earworm, fall armyworm) |
| Herculex 1 | Cry 1F | European corn borer, southwestern corn borer, western bean cutworm, fall armyworm, black cutworm (also offers suppression of corn earworm) |
| Herculex RW | Cry34Ab1/Cry35Ab1 | Western, northern, and Mexican corn rootworms |
| Herculex XTRA | Cry 1F + Cry34Ab1/Cry 35Ab1 | European corn borer; southwestern corn borer; western bean cutworm; fall armyworm; black cutworm; and western, northern, and Mexican corn rootworms (also offers suppression of corn earworm) |
| YieldGard Corn Borer | Cry 1Ab | European corn borer, southwestern corn borer (also offers suppression of corn earworm, fall armyworm, stalk borer) |
| YieldGard Rootworm | Cry 3Bb1 | Western, northern, and Mexican corn rootworms |
| YieldGard Plus | Cry 1Ab + Cry 3Bb1 | European corn borer; southwestern corn borer; and western, northern, and Mexican corn rootworms (also offers suppression of corn earworm, fall armyworm, stalk borer) |
| YieldGard VT Rootworm | Cry 3Bb1 | Western, northern, and Mexican corn rootworms |
| YieldGard VT Triple | Cry1Ab + Cry 3Bb1 | European corn borer; southwestern corn borer; and western, northern, and Mexican corn rootworms (also offers suppression of corn earworm, fall armyworm, stalk borer) |

[1]The traits for herbicide resistance or tolerance are not listed in this table.

insect or brand of corn grown. For transgenic rootworm-protected corn, the EPA requires that the refuge be placed within or adjacent to the field of Bt corn. For transgenic corn borer-protected corn, the EPA requires that the refuge be planted within ½ mile of the field of Bt corn. We strongly encourage corn growers to plant their refuges, regardless of the target insect, in the same fields where Bt corn is planted. Planting non-Bt refuges within fields of Bt corn will promote better mixing of the insect populations from non-Bt corn refuges with insects that survive in Bt corn.

It is also important to note that one brand of Bt corn cannot be used as a refuge for another brand of Bt corn for the same target insect. In other words, Herculex RW corn cannot be used as a refuge for YieldGard Rootworm corn, or vice versa. However, transgenic corn borer-protected corn can be used as a refuge for transgenic rootworm-protected corn, and vice versa, because the Bt proteins expressed in the two different types of corn are targeted for different insects. For example, a YieldGard Corn Borer hybrid can be used as a refuge for a Herculex RW hybrid (but not for a Herculex XTRA hybrid).

There are other, more specific requirements for both corn borer- and rootworm-protected corn that are not included in this paper. We refer you to the original biopesticide registration action documents for many other specific details about registered Bt events for insect control.

## What About Soil Insecticides?

In 2007, most farmers will continue to apply soil insecticides for control of corn soil insects, and many producers will apply soil insecticides to their non-Bt corn refuge acres. However, as the acreage planted to Bt corn (including triple-stack hybrids) increases, the acreage of corn treated with soil insecticides will decline. This outlook for a shrinking market for soil insecticides has greatly slowed the development of new corn soil insecticides; there are few chemical soil insecticides under development.

Corn producers in the Midwest have relied on soil insecticides for rootworm control for decades. Throughout the decades of their use, there have been some spectacular, widespread failures of some products to control rootworm larvae for various reasons (e.g., development of rootworm populations resistant to insecticides, enhanced microbial degradation). Most of the soil insecticides currently available for control of corn soil insects are reasonably consistent in their efficacy against corn rootworms and some of the secondary insect pests. However, environmental conditions may greatly affect the efficacy of soil insecticides, and control failures with the modern products have occurred as a consequence. In addition, there are concerns about the persistence of soil insecticides applied in early April. Nonetheless, data published from many sources over the years substantiate that soil insecticides are usually reliable products for rootworm control.

We will continue to recommend the use of both soil insecticides and transgenic Bt corn hybrids for rootworm control, when needed. Soil insecticides for rootworm control offer a couple of distinct benefits. Soil insecticides applied to non-Bt corn refuge acres protect against corn rootworm larvae and satisfy IRM requirements. Additionally, the availability of multiple active ingredients for control of corn rootworms reduces the selection pressure of any one active ingredient on rootworm populations and provides alternatives for rootworm management. Significantly fewer alternatives will limit our responses if widespread product failures occur.

## Concluding Remarks

One of the best ways to reduce selection pressure on a pest population is to use a control product only when necessary (e.g., pest insect density has exceeded an economic threshold). There are fully developed protocols and guidelines for sampling for western corn rootworm adults in both corn and soybeans to determine whether a rootworm larval control product will be necessary the following year. Many previous studies in midwestern states have shown that only about one-half of the corn acres harbor economic infestations of corn rootworms annually. The development of the variant western corn rootworm that lays eggs in soybeans and the variant northern corn rootworm that undergoes extended diapause are reasons to re-examine the annual levels of infestations of corn rootworms. However, it is certain that not all corn acres need to be treated with a soil insecticide or planted to a Bt corn hybrid for rootworm control. Using a rootworm control product only when it is needed is both economically and ecologically sound.

The other primary strategy for reducing the selection pressure that Bt corn may place on corn rootworm populations is to comply with IRM requirements, a strategy endorsed and explained thoroughly by the National Corn Growers Association (http://www.ncga.com) and all state corn growers associations. Stewardship of all of our rootworm control products now should ensure their use well into the future.

## References

Fernandez-Cornejo, J., and M. Caswell. 2006. *The First Decade of Genetically Engineered Crops in the United States.* USDA Economic Research Service, Economic Information Bulletin, Number 11. Washington, DC.

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# Who's Your Neighbor?

*Jack Erisman*

*He who reviles his neighbors has no sense, but the intelligent man keeps silent.*

—Proverbs 11:12

Our culture has nearly transcended the time when neighbors are a large part of our support system, be it physical or spiritual. Most of us consider neighbors as those geographically close to us; however, rural and urban evolution and communications and travel technology have made many of us neighbors who didn't necessarily choose such circumstances.

Organic ideology and the market influence of more specialty crops are permeating the countryside. This presents a diversity in which profit potential and livelihood and/or lifestyle can be greatly challenged, regardless of which side of the issues one may be on.

Each of us needs to diligently seek the information necessary to keep us out of harm's way. It will be much more palatable and psychologically reassuring if we really do understand each other's individual pursuits. Hopefully, out of these efforts, some healthy mutual respect will prevail. Having that understanding and respect will allow us to objectively execute our undertakings without infringing on the welfare of each other.

# Managing the Risks of Custom Application: An Industry Perspective

*Jean Payne*

Custom application is an integral part of the commercial crop protection industry. Although this service normally is bundled with the purchase of a crop protection product, with the erosion in profitability in the crop protection sector, custom application may be a service that will stand on its own in terms of a profit center for agrichemical retailers. *CropLife* magazine's recent survey of the top 100 agricultural retailers suggests that the value of the crop protection market to agricultural retailers dropped $800 million from sales figures reported in 2005. That's troubling, but the good news is that custom application service overall has expanded for most dealers as evidenced in increased equipment investments and acres serviced. Something has to take up the slack for the devaluation of crop protection products, and custom application has the potential to become a more profitable enterprise.

But inherent in custom application is risk: from a civil, environmental, and even criminal standpoint. The environmental activists, who are dogged in their efforts to reduce and even eliminate pesticide applications, have applied numerous strategies to raise the risk level within our industry.

Illinois had the distinction in 2005 of being the first state in which an agricultural retailer and member of the Illinois Fertilizer and Chemical Association (IFCA) was subjected to criminal charges by the U.S. Environmental Protection Agency for an alleged spray drift violation. In this case, constant letter-writing and emotional appeals over a 5-year period by a person who felt wronged by a pesticide application resulted in Region 5 filing charges against the commercial applicator, the licensed operator, and the company itself. The fact that EPA filed charges is not so shocking, but the fact that the charges were *criminal* was. Never in the history of enforcement has a pesticide application incident been pursued in a manner that could potentially result in a federal felony conviction. This means the commercial applicator and operator could end up in federal prison and face lifelong branding as felons, just for doing their jobs. The implication for these two men and the company was frightening; the impact of the case on the custom application industry as a whole could fundamentally affect the future of the pesticide industry.

In the end, the vigorous defense presented by the agricultural retailer prevailed, and a federal judge dismissed the case. It was a victory for the agricultural retailer and the industry, but the defense costs exceeded $200,000. In this case, our industry was very fortunate that this agricultural retailer had the resources to defend itself and prevail. Had the retailer lost this case, can you envision your company trying to hire commercial applicators to work for you, knowing that legal precedent had been set that could subject them to prison time for applying chemicals? Would anyone want to work in our industry at all when faced with this possibility? Had this case gone the other way, the environmental groups who are already notorious for using the judicial system to influence public policy would have seized on every opportunity to brand our industry as criminals for applying pesticides. We would constantly be defending ourselves in a court of law.

And when it comes to "branding" our industry, the environmental groups have recently been successful in coining a new phrase for pesticide application: "criminal trespass."

This is another attempt to influence the emotions of the public when it comes to pesticide application. As a nation, we have little sympathy for people who infringe on our property without permission. Branding pesticide applications as "criminal trespass" implies that our industry has no regard for someone else's property. Activists want the public to believe that "criminal trespass" of pesticides will result in "multiple chemical sensitivity" syndrome for anyone living in an agricultural area. You will see the term "criminal trespass" more and more both in the courts and in the public policy debate, so be prepared to respond if you get criticized or questioned.

The U.S. government has determined that proper and necessary pesticide applications are legal, not criminal. Producers have the right to protect their crops. And professional custom applicators are best equipped to handle the application of agrichemicals, taking into account the risks and responsibilities inherent in each application event.

As a professional custom applicator, how do you best manage your risk when the stakes have gotten so high? There is no form you can have your customers sign to absolve you of risk. But as a bonded, licensed, and trained commercial applicator, your advantage over private applicators is that you do take on the risk and liability of the application itself. I say "advantage" because it is an opportunity to present the value of this service to your customers and to charge accordingly. Charging for services is not something our industry has been very successful at, but, over time, this can change. Committing yourself to informing your customers about your liability and the associated costs will eventually work its way into the psyche of the agricultural producer. Let me provide an example.

In 2005, some producers made an attempt to seek approval of a policy that would direct the Illinois Farm Bureau to lobby for changes in the Illinois Pesticide Act to enable private applicators to spray for hire but without having to be licensed as a commercial applicator or have the required insurance. From a farmer's perspective this would be great, right? What private applicator with their own sprayer wouldn't want the opportunity to get paid for application services without being subject to the cost of the commercial license and insurance?

The IFCA and our members engaged in this debate with members of the Illinois Farm Bureau and worked with producers to present reasoned arguments against the policy. If farmers understood the stakes, would they really want to take on the liability that custom applicators deal with on a daily basis? Would that really be good for farmers? A majority of the producers decided it would not be, and the idea was soundly defeated by the Farm Bureau's voting delegates. Why? Because, over the years, the IFCA and our members have been very involved in educating not only farmers but also legislators and the general public about the professionalism of custom applicators and the increasing liability we face when we apply agrichemicals. It paid off in this instance because we have been able to "brand" ourselves as consummate professionals when it comes to agrichemical applications. If we remain committed to stewardship, to communication, and to promotion of practices that reduce the likelihood of drift, our image and our ability to protect the custom application industry will remain strong.

Is it a perfect world out there? No, not by any means. We know that some people skirt the law regarding custom application versus private application. But we are no different than any industry because regulations serve mostly to govern those who obey the laws. In a free society, there aren't enough law enforcement officials to track down everyone who disobeys the law.

Therefore, voluntary compliance is crucial; doing the right thing is important. As maddening as it is when people flout the law, it usually catches up with them at some point. You may not read about it in the paper, but the scales do balance. If not, the custom application business would cease to exist at all and certainly would not be growing. We provide a valuable service to producers and to society. Although it seems thankless at times, I can tell you it is appreciated by many in the both the private and public sectors. Custom applicators are often taken for granted; that's a sign that we are doing things right.

Our industry does not have an easy answer to the issue of liability. Custom applicators will continue to be targeted by activists and by government agencies that are influenced by political agendas. As an applicator your best defense—and offense—is to document your practices, make sound decisions, and promote professionalism. Define your image with your actions and with your words. In Illinois, our industry has been successful in maintaining a strong agrichemical application industry despite the fact that our legislature and state agencies are increasingly becoming governed and influenced by a very urban population base. Our ability to survive in this challenging environment is directly influenced by our

commitment to stewardship and the fact that we stand behind our principles.

In the end, whether in a court of law or in the court of public opinion, no one can tarnish your image overnight unless you allow it. Stand up for your principles and your professionalism, and you can limit your liability in the long run.

# Surviving on the Fence Between Emerald City and Oz

*Donald Meyer*

## About the Title

I was invited to speak at this conference about the challenges caused by the urban sprawl that continues to encroach on agricultural areas of McLean County. Like most Illinois counties, McLean has an increasing number of new residents who have moved into the rural area, just far enough away to escape the rigors and chaos of urban neighborhoods. These former urbanites sometimes are not aware of the "challenges" that sometimes go along with the "opportunities" of living in the country. It is a situation not uncommon in most of the United States, and there are even brochures written for the new rural dwellers, such as the "Code of the West" or the "Code for Midwest Rural Living," to share what rural residency can be like.

Extension speakers (like me) may walk rather unusually because of the many years spent straddling a fence between "Emerald City," as in the urban dream, and the more typical rural life, out in the farmland of "Oz." Some days that fence is a pleasant board fence on which to be seated, with the research-based and environmentally appropriate aspects of farming in the county on one side and the rights of a nonfarm resident, either on the edge of sprawl or on an 5-acre island plot in the middle of a large farming county, on the other. Other days that same fence can be a bit "chafing," as if it were made of barbed wire, because there are unfortunate accidents caused by pesticide application mixed with nature (drift) that cause rifts between neighbors. Finally, on a few days each year, the fence feels more "electric," when a current alleged incident fuels a long-standing dispute between neighbors—almost as if it were the Hatfields and McCoys fighting again—with pesticide use as the latest chapter in the land rights issue.

Since the time I agreed to present a perspective for this conference, another issue has been added, which is also related to the use of pesticides—a situation that is becoming increasingly common in McLean County as a result of the more conventional "pesticide-dependent" approaches to farming in commodity agriculture and the increasing acres being shifted toward an organic consumer.

Many of the following points are applicable to the dilemma of pesticide application challenges.

## Speaker Perspectives

I have served McLean Couny citizens for almost 24 years, since I left teaching and became first the agriculture Extension adviser and now the county director for the Extension office in McLean County. My background is in farming; I grew up in McLean County and obtained agricultural education degrees (bachelor's and master's). In my role with the Extension office, I serve county farms and agribusinesses and also assist urban clients with horticulture programming. McLean County is a rapidly growing county in terms of population, with a hub metropolitan area of Bloomington/Normal.

## McLean County Agriculture Background

Nearly every year, McLean County continues to be the nation's top-producing county for corn and soybeans, recently producing more than 58 million bushels of corn and more than 14 million bushels of soybeans. In 2003, McLean County had more harvested corn acres than 26 entire states did, and we produced more corn than 30

entire states! McLean County also outproduced 28 states in soybeans in 2003. The 2002 U.S. Census of Agriculture lists 1,442 McLean County producers farming more than 688,000 acres of farmland. Annually, more than 200 million bushels of agricultural commodities are produced here, with farm income derived at 87% from crops and 13% from livestock. In terms of total market value of production, McLean County ranked 138th out of 3,078 counties in the 2002 U.S. Census of Agriculture.

## McLean County Urban Background

Even with all of that agricultural production, McLean County's urban growth has been on the rise. The U.S. Census reported a county population growth of 16.5% from 1990 to 2000, almost double the rate for Illinois. The county has the 13th highest population in the state, with 150,453 residents in 2000, and has gained 21,253 residents since the previous census. The projected population for 2004 is 158,006 residents. Our growth rate from 1990 to 2000 was the 10th fastest county growth rate in Illinois.

## Now—The Situation

You may know the situation well! We depend on pesticides to provide inexpensive input costs and minimum tillage approaches for most farms in Illinois. Pesticides save time, enable farming of more acres, reduce erosion, and minimize fuel costs. Years ago, product uses were based on a fieldwide, large-volume, broad-spectrum, "if it crawls, flies, or walks, it will kill them" type of chemistry. Today, products are more specific-pest targeted, applications can be site-specifically satellite controlled, and available products are more ecologically appropriate.

However, even with these advances in product chemistry and site application, many nonfarm residents do not appreciate what agriculture is doing and how it is doing it. Countless news features every year intensify the opinions of nonfarm citizens, and those in agriculture have become further removed from the 98% nonfarm citizens.

As the U.S. population continues to shift from the agrarian society of yesteryear and as the number of farmers as a percentage of the whole population continues to reduce, our message is conveyed with even more difficulty to a nonfarm public. In agriculture, farmers are using research to back up their methods, are concerned about protecting the growing crops and environment, and are furnishing what is still believed to be one of the safest and cheapest food supplies in the world. Yet they do need to be aware of common perceptions of agriculture. In addition, farm operators *must* be conscious of their rights and responsibilities regarding the use of pesticides and at the same time must remain conscious of the rights and responsibilities of their nonfarm or organic-farming neighbors.

To begin to solve the problem, solutions may be best offered as a review of generally accepted rights and responsibilities.

Conventional farmers in "Oz" generally have the following rights on the agriculturally zoned land they own or manage. They can

- grow whatever "lawful" crop they wish
- work in the fields any day or under any conditions
- graze whatever livestock they wish
- protect their growing crops in any lawful way necessary
- harvest the crop whatever day they select
- drain their water onto others' property, as long as it doesn't interfere with natural drainage patterns

With those rights come responsibilities pertaining to that same land. Farmers have the responsibility to

- keep plants growing inside property lines
- keep livestock within property lines
- keep crop protection products within property lines
- accept water that naturally flows toward their property

The home owner or organic farmer living on the edge of "Emerald City" or out in the country of "Oz" also has certain rights and responsibilities. Nonfarm residents and organic farmers adjacent to traditional farms have the right to

- grow whatever legal plants they wish to grow on their property
- enjoy air and water that is not affected by adjacent activities
- not be threatened by drift from crop-protection products

Similarly, nonfarm residents and organic farmers have the responsibility to

- keep their plants growing and personal property within property lines

- keep their children and animals away from growing crops and livestock
- not trespass onto farm property for hunting, ATV riding, or other leisure activities

When one person's rights are infringed on by another's activities, conflicts can occasionally arise. Remember the standard rule, "Your rights end where my rights begin!"

## Real-Life Situations

Let's review some real-life situations that have occurred:

***Situation 1:*** Farmer Smith sold off a farmhouse and 5 acres no longer needed by the farming family. Nonfarm resident Jones purchased the property surrounded on three sides by farmland. Smith now farms up to the property line and sprays within a 30-inch row width of the Jones property.

***Situation 2:*** Farmer Smith has farmed his property for more than 30 years. A neighbor just sold the adjacent property for development, and now a line of houses have been built along the unfenced border. Most of the adjacent property owners are more than one generation from farming and do not like the dust, noise, and occasional pesticide use on the farm.

***Situation 3:*** Farmer Smith has farmed his property for more than 30 years. Farmer Jones just switched from conventional commodity farming to organic vegetable production.

***Situation 4:*** Farmer Smith finally "caved in" to sprawl and development and sold 40 acres to a developer. The developer experienced a slowdown and could not get houses built promptly. Developer Jones hired lawn care company Meyer (or agribusiness firm Meyer) to treat the property with herbicides because weeds have overgrown the former farmland, and the city ordinance requires mowing or weed control.

## What Can We Do?

Regardless of the situation (whether similar to one described above or another, unique situation), there is always more than one approach to trying to meet this growing challenge.

Farmers and applicators need to avoid the "Rambo" approach, aggressively trying to muscle their way into the future, and lose the attitude of "we were here first." The liabilities and costs to replace consumer products damaged by pesticides will likely outweigh any benefits to that approach. Once a pesticide is alleged to have drifted off-target, the "victim" generally opens a watchful eye to all of the outdoor plants. All of a sudden, concerns about myriad types of "nonchemical" plant damage—even from routine, naturally occurring plant diseases related to weather that ordinarily might have gone unnoticed—somehow become associated with the pesticide application.

As always, the past seems simpler. Years ago, if livestock was grazed on farm property, the fence law required property owners on both sides of the property line to maintain a working fence to protect the rights of both owners. Because we cannot easily "fence" pesticides, what precautions might be considered to prevent problems?

- Apply only according to pesticide label instructions and when weather conditions are appropriate, as specified on the label?
- Apply products least likely to drift, if such choices are available, or with approved additives to minimize the drift?
- Discuss during the off-season which farm products will be used?
- Agree on a "demilitarized" zone from each side of the line? (For example, no "at-risk" vegetables or ornamentals to be grown, or no farming to within so many inches of the property line)?
- Establish a good relationship by sharing "rights" in exchange for the "risks" (post-harvest gleaning of fields, hunting rights, ATV or horse riding, tractor rides, snow plowing furnished, sharing of garden produce grown, hiring of family members to assist with the farm, etc.)?
- Alert the nonfarm resident or organic producer when spraying is scheduled?
- Provide educational materials about pesticides, farming methods, and integrated pest management practices?
- Work with authorities to provide zoning protections (including "agricultural zones") to limit sprawl?
- Hire an agribusiness company or cooperative to do the pesticide application to pass along the liability?
- Use pesticides only as needed, as part of an integrated pest management program?

- Work with Realtors and obtain their assistance in explaining agricultural zoning and life in that zone?
- Other ideas?

## What Is the Role of Extension?

University of Illinois Extension provides workshops and materials (publications, CDs, workbooks) to assist in training farmers and commercial pesticide applicators about pesticide safety. Extension's role is education of pesticide applicators, property owners, and residents, and we can also assist with providing researched-based recommendations to determine whether pesticide application is appropriate.

Educational resources about spray drift are available on the Web at http://www.pesticidesafety.uiuc.edu/facts/drift.html.

In addition, we can assist other local groups in sharing information and building trust between nonfarm citizens and the agricultural community with agricultural awareness activities. We can also provide education on these issues to decision-making authorities.

Extension involvement pertains largely to education about pesticide use or alternatives to their use. Occasionally, we process samples of agricultural or horticultural plants that may be showing a pesticide drift symptom or another problem that may have surfaced due to a concern about potential drift. Enforcement, however, belongs to the Illinois Department of Agriculture, with follow-up from an area IDA field representative after a written complaint has been filed with the department.

In conclusion, we need to continue to work together to increase consumer awareness of agriculture, ensure research-based information to support an integrated pest management program, and educate all pesticide applicators about following label directions and safe handling and application of pesticides.

# A Regulatory Perspective on the Rural Agricultural Production/Urban Interface

*Gerald Kirbach*

In recent years, the Illinois Department of Agriculture has investigated several complaints filed by "nonagricultural" residents related to alleged pesticide drift onto nontarget areas. Many home owners are attracted to life in the "country" and assume it is a pristine environment with beautiful crops growing fresh produce from their garden and orchards. Producers assume that their "new" neighbors understand modern crop production and the use of pesticides. Usually, neither assumption is true.

Many rural home owners with an urban background plant garden plots to supply their needs during the growing season; these plots range from small to extremely large. Whenever problems arise in their produce area, their first thought is that a pesticide application made by a neighboring producer is the cause. Consequently, a complaint is filed. Many times, a complaint is based on an odor that was experienced during the application. The assumption is that if the pesticide can be smelled, there is contamination on their property and the produce is no longer viable for consumption. This determination occurs even when there is no damage observed to the growing plant material. Some rural residents do not even realize that the producer used the same active ingredient (e.g., glyphosate) that they used in their own lawn, garden, or orchard.

Many times, producers feel pressure to get the crop planted and apply pesticides by a certain date, particularly when there have been weather-related delays. As a result, poor decisions may be made, possibly resulting in the presence of a pesticide in a nontarget area (drift). Frustrations may arise in producers because (1) of the late planting period, (2) the "neighbor" doesn't seem to understand that the crops have to be planted, (3) they were there first, and (4) delays could affect their standard of living if crop yields are reduced. The neighbor seems insensitive to the compelling need of the producer to plant the crop and to the diminishing window to maximize yields, and doesn't understand that there is little or no potential threat to his or her health or property.

Failure of a producer to respond to a neighbor's inquiry or complaint in a diplomatic manner almost always results in a complaint being filed with the Illinois Department of Agriculture. Lack of understanding of agricultural production does not provide a basis for a producer to respond improperly to the inquiry or complaint. Statements such as "It is none of your business" or "I don't care if you like it or not" will only ensure escalation of the complaining individual's desire to seek further assistance.

Many times, a heated exchange occurs between the two parties and builds into a confrontational relationship. Producers have been accused of refusing to provide information about the active ingredients applied to the neighboring fields. The rural resident will plant garden plots next to the property line to maximize the potential of drift on his or her property. Finally, throughout the entire process, the department is saddled with the burdensome task of investigation, collecting evidence (including interviews), and making a final determination regarding pesticide misuse. Often, the parties interviewed are hostile, and claims on both sides can be exaggerated. Many times, neither party ends up happy or satisfied with the outcome. The rural resident simply wants restitution and assurance that the incident will not be repeated. The applicator is frustrated with the minimum level of enforcement, which

is an advisory letter indicating that there was a minimal level of misuse but not enough for the department to pursue a more significant enforcement action.

The department's investigation process includes all resources available to make a final determination consistent with the mandate specified within the Illinois Pesticide Act, such as interviews, collecting samples for analysis with sensitive analytical equipment, taking photographs, and ensuring that the application was made in compliance with state and federal laws. The Illinois Pesticide Act contains a clearly defined matrix with a point system for determination of penalties. It contains various sections that are scored by a group of three staff members. The results are summarized and a finding is issued, based on internal review.

A few years ago, a dealer failed to adequately respond to a neighbor's complaint concerning drift of a pesticide to their property and animals. The applicator ignored the concern, felt the situation could not be resolved, and applied pesticides in a similar manner the following year. The department investigated the complaint and found that drift had occurred during both applications. The presence of a pesticide was found through analysis of soil and plant samples. The situation escalated to a point that criminal charges were filed by the United States Attorney General's Office, and an investigation was conducted by the Criminal Investigation Division of the United States Environmental Protection Agency. The case was eventually brought before the courts and resolved, but attorney fees were large for both parties.

## Organic Production

Producers today are looking for marketing niches or specialty markets that can provide a higher return to their operations. These options may include establishment of vineyards or vegetable production. A growing segment is organic production of fruits and vegetables. The marketplace has become more health conscious and is willing to pay a premium for commodities grown without the application of pesticides.

This trend has created some opportunities for agricultural production and some obstacles for production by conventional means. A concern that seems to arise during any complaint investigation involving organic production centers on the long-term impact. Will an alleged exposure to pesticides remove organic certification in future years and, if so, for how long?

The department does not have any means to evaluate these situations, particularly if no background samples were collected and analyzed prior to the implementation of organic production. Today's analytical equipment has the capability to detect trace amounts of active ingredients in parts per trillion. Should the determination be based on metabolites of the active ingredient as it breaks down? What is the impact on soil microbial activity to break down the active ingredient in a timely manner? Does the level of detected active ingredients have a direct impact on tolerances of crops planted the following year? All of these questions, while pertinent, are not easily answered with the available data.

## Summary

Currently, the department makes a determination that a pesticide was misused based on the evidence collected after the complaint is filed. To date, there has been no determination of damage based on subsequent loss of income, due to a lack of statutory authority in this arena. Any producer who wishes to be compensated for damage during the current growing season or subsequent years will be forced to seek restitution through the civil court system.

A more immediate solution to the problem can be achieved only through mutual cooperation, diplomacy, and outreach from all groups involved. Conventional producers have had success in producing a commodity near organic production through advance work and outreach. Identification of sensitive areas, strong communication between both parties during the planting season, and a commitment to work together toward a common goal of economic viability through their respective choice of production, either conventional or organic, have brought success in some areas.

Failure to work together will almost always result in adversity, confrontation, and frustration with each other. If the department is included in the complaint process, a determination of whether pesticide misuse occurred will indeed be made, but it will not necessarily resolve the situation to everyone's satisfaction.

# Identifying and Protecting Organic Farms from Contamination with Prohibited Substances

*Cissy Bowman*

## What Is an "Organic" Farm?

Farms that sell food labeled "organic" must be certified by a USDA accredited certifying agent according to the rules of the National Organic Program (NOP). The NOP was established under the Organic Foods Production Act (OFPA), which was passed as part of the 1990 Farm Bill. The intent of the regulation was to create a consistent meaning for the word "organic."

The NOP was implemented on October 21, 2001. The rule is set forth in the Code of Federal Regulations (CFR), Part 205. Full and updated copies of the act and the rule are available on the NOP Web site at http://www.ams.usda.gov/nop. The NOP rule is the same for all certifiers in all states.

Drift is the main concern for pesticide applicators and is defined in the rule as "the physical movement of prohibited substances from the intended target site onto an organic operation or portion thereof."

Organic farms, in order to be certified, must submit an Organic System Plan (OSP) to the certifier for approval. This plan addresses all inputs used on the farm as well as how the operator intends to prevent drift or contamination with prohibited materials. To become certified, the land must have been free of the use or application of prohibited substances for at least 3 years. "Application" need not be intentional use by the farmer. Drift can be unintentional application.

Under CFR §205.400, a person seeking to receive or maintain organic certification under the regulations must "(f) Immediately notify the certifying agent concerning any: (1) Application, including drift, of a prohibited substance to any field, production unit, site, facility, livestock, or product that is part of an operation; ..."

## Scope of Certification

There are currently four types of organic certification under NOP: production (farm), livestock, wild crop production, and handling facilities. A pesticide applicator may find himself or herself working on or near any one of these operations. Prohibited substances have the potential to contaminate not only soils or plants but also animals and the food-contact surfaces of processing machinery, storage facilities, harvest equipment, and transportation vehicles. The potential for contamination exists anywhere organic food grows or with anything it touches throughout its planting, growth, harvest—all the way to its sale to the consumer.

## What Is Prohibited?

According to CFR §205.105, a product that will be sold or labeled as "100 percent organic," "organic," or "made with organic (specified ingredients or food group(s))," the product must be produced and handled without the use of synthetic substances and ingredients unless they appear on Environmental Protection Agency's national list of allowed substances. There are also some natural or "nonsynthetic" substances that are prohibited in §205.602 or §205.604.

A synthetic, under the rule is "a substance that is formulated or manufactured by a chemical process or by a process that chemically changes a substance extracted from naturally occurring plant, animal, or mineral sources,

except that such term shall not apply to substances created by naturally occurring biological processes."

In general, this means that most synthetic pesticides and fertilizers, and those that contain synthetic inert ingredients that are not on EPA List 4 (generally recognized as safe, GRAS), are prohibited. Prohibited materials include synthetic seed treatments. Use of or contamination with prohibited substances results in certification being denied for 3 years. There are exceptions under the Emergency Treatment Program. Under CFR §205.672,"when a prohibited substance is applied to a certified operation due to a Federal or State emergency pest or disease treatment program and the certified operation otherwise meets the requirements ... the certification status of the operation shall not be affected as a result of the application of the prohibited substance: Provided, that: (a) any harvested crop or plant part to be harvested that has contact with a prohibited substance applied as the result of a Federal or State emergency pest or disease treatment program cannot be sold, labeled, or represented as organically produced ..."

## Where Are the Organic Operations?

Organic certification has grown very rapidly and encompasses the entire United States and much of the rest of the world. Increasing demand will result in continued growth. Some companies are literally out looking for new organic farmers. To the best of my knowledge, Illinois currently has about 200 certified operations, consisting of all types of certification.

The best way to avoid accidental application (drift or otherwise) of prohibited substances on an organic operation is to know where they are. This can be best done by a little research before taking any chances. The NOP Web site has a list of certifiers and their contact information at http://www.ams.usda.gov/nop/CertifyingAgents/Accredited.html. Some certify across the country. Others certify only in a state or a region. The primary certifiers operating in Illinois at this time are Indiana Certified Organic (ICO) and the Organic Crop Improvement Association (OCIA).

In the 2002 Farm Bill, appropriations were made to offset the cost of certification. These funds were used throughout 2006 and administered by state departments of agriculture. The Illinois Department of Agriculture should be able to provide a list of operations that received cost share. This list may include other certifiers' names and may help you in identifying them. The National Agriculture Statistics Service (NASS) also maintains a database of organic operations.

As part of an OSP, a certifier expects the operation to document its procedure for avoiding drift. This procedure may involve any of a number of approaches, as appropriate to the individual operation. Some operations post signs. Others send letters to notify potential applicators that their farms are organic. This procedure is fairly easy to do when dealing with county or state road maintenance crews, but it tends to get more difficult when neighboring farms use hired applicators. Communication is key to avoiding problems.

The most common preventive measure is the creation of a "buffer zone" on the organic farm. A buffer zone, under the regulations, is "an area located between a certified production operation or portion of a production operation and an adjacent land area that is not maintained under organic management. A buffer zone must be sufficient in size or other features (e.g., windbreaks or a diversion ditch) to prevent the possibility of unintended contact by prohibited substances applied to adjacent land areas with an area that is part of a certified operation."

Historically, a 25-foot buffer was considered to be appropriate. Over the years, however, we have realized that there is no magic number. The certifier and the farmer must identify what is right for the operation. A trained, on-site inspector will analyze and report on the effectiveness of the proposed buffer zone. The inspector may recommend that the buffer be increased or improved. In cases for which there is suspicion of drift or potential contamination, the inspector may recommend or perform a residue test.

In a handling operation, potential for contamination is most likely to occur inside the facility. As part of its OSP, a handler must identify what methods are used for pest control. If prohibited materials are used, there must be a process for, and records kept of, how organic products were protected. In general, we prefer to see such facilities use approved materials.

On farms and handling operations, if contamination is suspected, residue tests will be conducted. Such tests are costly, and contamination must be reported. According to CFR§205.671,

When residue testing detects prohibited substances at levels that are greater than 5 percent of the EPA's tolerance for the specific residue detected or unavoidable residual environmental contamination, the agricultural product

must not be sold, labeled, or represented as organically produced. The Administrator, the applicable State organic program's governing State official, or the certifying agent may conduct an investigation of the certified operation to determine the cause of the prohibited substance.

## It's Not Just About Certified Organic Farms

There are people today who have gardens and lawns that they maintain organically. There are also organic farmers who are exempt from certification because they fit into the "small farm exemption." These are people who gross no more than $5,000 per year for the sale of organic products. These people are more difficult to identify than certified farmers; however, they often display signs notifying that they do not use pesticides. Such signs often display ladybugs or other beneficial insects, butterflies, and/or statements such as "Pesticide Free Zone" or "Organic Garden. Do Not Spray" (Figure 1). These signs are displayed for a reason and should be taken seriously. Damage can be done to noncertified land as well. Gardeners and home owners who choose not to use synthetic pesticides do so for many reasons and should be respected, as well.

## What Happens If Drift Occurs?

Drift of prohibited substances takes land out of organic production for 3 years. The next crop to be called organic cannot be harvested until at least 3 years after the date of the application or drift. This causes harm to the farmer because he or she will lose the organic premium. Prices for organic crops are higher than those for conventional crops. The damage to the farmer's marketing abilities will vary based on what is being produced and how much crop was contaminated.

It is important to keep in mind that drift can damage a farmer who is "transitioning" to organics, as well as a certified farmer. If it occurs in the transition period, it sets the farmer back 3 years. Identifying transitional farmers is difficult because they are not required to be certified or inspected, but that does not mean they should not document their practices. Indeed, they are required to keep records and submit them to the certifier upon initial application. Transitional farmers need to monitor drift as much as the certified farmer does.

Handling operations can usually find a way to clean up contamination or change their system plan to stop the problem. Their certification is based on their willingness to come into compliance with appropriate methods and/or materials and is not based on years of "abstinence" from using prohibited materials. The only way to fail to meet the standards is to refuse to meet requirements. Thorough clean-ups and adoption of approved or allowed alternatives are the answers to "mistakes."

## When Accidents Happen ...

Applicators do not go out of their way to apply materials unless they have been hired to do so, but accidents do happen. ICO has seen some cases that have helped us create a process for reacting to witnessed or suspected drift. For example,

- A herbicide is being applied to a farm that neighbors an organic farm. The organic farmer is outside and notices that the spray is going onto his crops. Although he has a buffer, he knows there is contamination with a prohibited herbicide to his nonbuffer, organic crops.

  This farmer took immediate action. He contacted his neighbor to find out who was doing the application and what was being sprayed. He obtained information about wind speed and direction that day. He contacted the company that hired the applicator and told them he had witnessed drift. He took pictures of the subsequent damage. He notified his certifier and asked how his plan needed to be changed based on the drift. More than one-third of his field showed signs of drift. He worked out the necessary changes on certification for that part of his field with his certifier. Payment for damages was arranged between him and the company who hired the applicator. The amount has not been disclosed but was likely based on the difference in

organic price compared to conventional price for the crops he will raise there for the next 3 years. In this case, there was no doubt about contamination because it was witnessed and there was obvious damage to the crop.

- An insecticide has drifted onto an organic farm. Although no one saw the application actually happen, there has been known use of this insecticide on neighboring farms and, in some cases, overhead spraying. The organic farmer and/or certifier suspects contamination.

  In this case, a residue test would probably be performed. The certifier would determine whether the test was needed. Testing in these cases is handled very seriously.

Under CFR §205.670,

(b) The Administrator, applicable State organic program's governing State official, or the certifying agent may require preharvest or postharvest testing of any agricultural input used or agricultural product to be sold, labeled, or represented as '100 percent organic,' 'organic,' or 'made with organic (specified ingredients or food group(s))' when there is reason to believe that the agricultural input or product has come into contact with a prohibited substance or has been produced using excluded methods. Such tests must be conducted by the applicable State organic program's governing State official or the certifying agent at the official's or certifying agent's own expense.

(c) The preharvest or postharvest tissue test sample collection pursuant to paragraph (b) of this section must be performed by an inspector representing the Administrator, applicable State organic program's governing State official, or certifying agent. Sample integrity must be maintained throughout the chain of custody, and residue testing must be performed in an accredited laboratory. Chemical analysis must be made in accordance with the methods described in the most current edition of the *Official Methods of Analysis of the AOAC International* or other current applicable validated methodology determining the presence of contaminants in agricultural products.

(d) Results of all analyses and tests performed under this section:

(1) Must be promptly provided to the Administrator; except, that, where a State organic program exists, all test results and analyses shall be provided to the State organic program's governing State official by the applicable certifying party that requested testing; and

(2) Will be available for public access, unless the testing is part of an ongoing compliance investigation.

(e) If test results indicate a specific agricultural product contains pesticide residues or environmental contaminants that exceed the Food and Drug Administration's or the EPA's regulatory tolerances, the certifying agent must promptly report such data to the Federal health agency whose regulatory tolerance or action level has been exceeded.

I cannot stress to highly the importance of identification of the

- borders of the location you intend to spray or treat with pesticides,
- locations of organic farms, and
- wind speed and direction at the time of application.

## Other Sources of Contamination

It is possible for organic products to be contaminated without drift being the cause. The rules call this "unavoidable residual environmental contamination" (UREC), which is defined as "background levels of naturally occurring or synthetic chemicals that are present in the soil or present in organically produced agricultural products that are below established tolerances."

When residue testing detects prohibited substances at levels greater than 5% of EPA's tolerance for the specific residue detected or unavoidable residual environmental contamination, the agricultural product must not be sold, labeled, or represented as organically produced.

We have seen drift from with synthetic fertilizer applications, as well. Organic farms are required to rely on farm practices that build fertility and soil health through the use of natural methods. Such practices include rotations, cover crops, and the application of plant and animal materials or mined substances of low solubility. In some cases, mined substances of high solubility and synthetic substances are allowed if they are included on the national list of synthetic substances permitted for use in organic crop production as established in CFR §205.601. Producers may not use any fertilizer or composted plant and animal material that contains a synthetic substance not included on the national list.

## What About State or Federal Emergency Treatment Programs?

Under CFR §205.672, when a prohibited substance is applied to a certified operation due to a federal or state emergency pest or disease treatment program, and the certified operation otherwise meets the requirements of this part, the certification status of the operation shall not be affected as a result of the application of the prohibited substance. provided that "(a) any harvested crop or plant part to be harvested that has contact with a prohibited substance applied as the result of a Federal or State emergency pest or disease treatment program cannot be sold, labeled, or represented as organically produced ..."

## How Do We Work Together?

Communicate with

- certifiers, who are required by law to provide the public with basic information about their certified operations. You have the right to ask any organic certifier for a list of their clients and locations.
- your state department of agriculture, which will have at least a partial list of certified operations based on cost share fund records.
- universities that have programs for organic and sustainable agriculture.
- extension offices, which may know of organic farmers in their area.
- U.S. government authorities such as USDA/NOP and the National Agricultural Statistics Service (NASS), which have Web sites and information on regulations, as well as statistics.
- owners of the operations on which you apply pesticides, who may know if their neighbor is an organic farmer or is in transition.
- regional organizations that educate organic or would-be organic farmers. There are several in the Midwest. Attending sessions at any of the organic conferences or those that include organics is a great way to extend your knowledge of how to prevent accidents and reduce liability.

Whether you believe in organics or not, it is a form of agriculture that is here to stay. From large to small, from mom-and-pop operations to the largest agri-businesses on the planet, we see people turning this direction. More and more land is in transition or currently certified than ever before. Part of "crop protection" must be protection of organic crops from drift, just as it is protection of crops in general from pests.

## Additional Information

- Appropriate Technology Transfer for Rural Areas (ATTRA): 800-346-9140; www.attra.ncat.org
- Indiana Certified Organic, LLC (ICOLLC): 317-539-4317; icollc@earthlink.net
- Independent Organic Inspectors Association (IOIA): 406-436-2031; www.ioia.net
- National Agriculture Statistics Service (NASS): http://www.usda.gov/nass

# Is Extension Delivering Relevant and Effective Integrated Pest Management Corn and Soybean Programs?

*Wendy Wintersteen*

In the fall of 2003, Iowa State University's College of Agriculture asked for statewide feedback in a review of the Iowa Agriculture and Home Economics Experiment Station—the college's research program and the associated extension programs. The college used results of the review to guide budget decisions and allocations for future research.

One critical priority that emerged from the review was the importance of keeping Iowa's farmers competitive and profitable, a theme reflected in the college's current strategic plan.

Because corn and soybeans are central to farmers' success in Iowa, the college began to develop an initiative to bring new focus to the needs of crop growers. Prior to the official start-up of the Corn and Soybean Initiative (CSI), the college surveyed corn and soybean growers and agribusiness professionals to better assess key research priorities and perceptions about information and education delivery.

## Highlights of the Survey

The 2004 survey involved telephone interviews with 400 randomly selected corn and soybean growers and 100 certified crop advisers (CCAs). The grower interviews were dispersed to provide a balance among Iowa's nine crop reporting districts. The growers farmed an average of 1,579 acres of corn and soybeans in 2003. The CCAs are professionals working for a variety of agribusinesses. They include fertilizer/agricultural chemical dealers, cooperative employees, seed dealers, independent crop consultants, seed company representatives, and farm managers.

The survey asked growers and certified crop advisers to provide sources they used for crop production information, then followed up with questions to evaluate Iowa State University's performance. Two findings are particularly relevant to the development of ISU's new Corn and Soybean Initiative:

- Both growers and CCAs rely on multiple sources for information on corn and soybean production. For growers, the vast majority (more than 90%) identify private-sector crop advisers as a primary source of information, ...
- ... while most of the crop advisers (more than 80%) identify Iowa State University as their primary source of information.

Overall, the survey results clearly reflect the emphasis Iowa State has placed for more than three decades on "training the trainer—taking advantage of existing partnerships with private agribusinesses to effectively deliver science-based production information to growers. This university–private sector partnership greatly multiples the impact of ISU research and continues to successfully and effectively reach farmers with needed information and programs.

Survey respondents were also asked what corn and soybean issues needed more research attention. Disease management and insect management were rated the highest in both groups. Growers and CCAs were asked whether they felt that ISU was moving in the right direction in providing useful information, in being responsive to their needs, and in being objective. In usefulness of information, 85% of growers and 84% of CCAs felt that ISU was moving in the right direction. In responsive-

ness, 83% of growers and 76% of CCAs felt that ISU was moving in the right direction. In objectivity, 86% of growers and 63% of CCAs felt that ISU was moving in the right direction.

Finally, respondents were asked to assign a grade to how well ISU was providing them with the information and support they needed to be successful in their corn and soybean operations or businesses. Of the growers, 77% assigned a grade of A or B. Of the CCAs, 85% assigned a grade of A or B. Those who did not assign an A were asked to suggest how ISU could improve its grade. For both groups, the most frequently mentioned comments were be more responsive, change research focus, and be more up to date.

## Planning and Development of the Initiative

The results of the survey have been used to guide Iowa State University in planning and development of its new Corn and Soybean Initiative. The initiative has been designed to improve responsiveness to partners' questions and concerns; provide a better research focus; enhance communications; and position Iowa State as a leading source for objective, science-based information to help corn and soybean growers thrive.

The mission of the ISU Corn and Soybean Initiative is to provide science-based crop production information to Iowa corn and soybean growers to increase their productivity and global competitiveness, while also conserving the environment. The goals of the initiative are to

- be the central access point for Iowa State University research and extension programs related to corn and soybean production;
- serve as an interdisciplinary catalyst to integrate Iowa State University resources that serve corn and soybean producers and related industries;
- develop meaningful public/private partnerships to accomplish its mission;
- integrate Iowa State University research and extension resources, expertise, and programs with those of commodity, agricultural, and government organizations to maximize opportunities;
- anticipate emerging technologies and issues that will affect corn and soybean production; and
- provide practical, research-based information and education about these issues to producers.

By coordinating Iowa State University's research and extension programs with commodity and farm organizations' efforts, other academic institutions, state and federal agencies, and allied groups, the Corn and Soybean Initiative leverages resources that benefit corn and soybean producers. The initiative has designed specific and formal partnership programs for different groups, organizations, or segments of the agriculture industry, with a specific focus on retail agribusinesses. A formal agreement is signed between the partners and the Corn and Soybean Initiative.

The Corn and Soybean Initiative partnership program agreement for retail agribusinesses is summarized below.

The retail agribusiness receives

- direct input into CSI's applied research agenda (a special, day-long retail partners' meeting with CSI representatives);
- a privileged line of communication and access through its own "partnership manager" (the partnership manager is an ISU staff person who is responsible for the retail agribusiness's CSI partnership relationship);
- priority with campus and field staff through the partnership manager;
- the benefits of CSI marketing and promotion—viewed by industry, farmers, and public as being part of the right way to farm;
- day-early e-mail about all CSI information releases; and
- priority on any applied research that the individual retail partner helps fund, along with branding of cooperative applied research funding (results are reported as the "[company name]/CSI applied research project," which provides higher credibility with the business's growers.

The retail agribusiness agrees to

- post CSI metal signs at all locations;
- assign one person to be the lead to meet and communicate with the CSI partnership manager;
- be a conduit for delivering the CSI messages to growers;
- "identity preserve (IP)" CSI information in all company Web sites, newsletters, etc.;

- co-host with ISU a CSI educational meeting for growers managing more than 1,000 acres; and
- agree to use the CSI logo according to guidelines (not changing the colors or proportions).

The Corn and Soybean Initiative was launched in December 2004 at the Iowa State University Integrated Crop Management Conference. Prior to the conference, agricultural retailers across the state were personally visited and asked whether they wanted to be formal partners with the new initiative. More than 20 retailers signed on prior to the December conference, and the initiative currently has 28 retailer partners. In addition, organizational partnerships have been established with the Agribusiness Association of Iowa, Iowa Certified Crop Adviser Board, Iowa Corn Growers Association and Promotion Board, Iowa Farm Bureau Federation, *Iowa Farmer Today*, Iowa Soybean Association, Iowa Crop Improvement Association, *Midwest Ag Journal*, and *Wallaces Farmer*.

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# Illinois Crop Protection Technology Conference Program

## Wednesday Morning, January 9

**All sessions in Illini Rooms A, B, and C**

(Requested: 1.0 CCA credit in Professional Development)

| | |
|---|---|
| 8:30 AM | **Welcome and Opening Remarks,** *Mike Gray* |
| 8:40 AM | **Preventing Poly Tanks from Cracking Like an Egg,** *Fred Whitford* |
| 9:30–9:45 AM | Break, South Lounge |

**Symposium: High-Production Soybean Management**

(Requested: 1.0 CCA credit in Crop Management and 1.0 CCA credit in Integrated Pest Management)

With more corn and less soybean acreage in 2007 and perhaps the near future, high-yielding soybean fields are important to help meet demand. Will new genetics, different production practices, and pest and disease management tools help soybean producers meet the demand? This symposium will focus on managing the soybean crop, pests, and diseases to achieve high-yielding and high-quality soybean.

| | |
|---|---|
| 9:45 AM | **Soybean Management for Maximum Yields AND Profits,** *Seth Naeve* |
| 10:10 AM | **Managing Soybean Cyst Nematode for Maximum Soybean Productivity,** *Greg Tylka* |
| 10:35 AM | **Foliar Fungicides and Fungicide Seed Treatments: Getting that Return on Investment,** *Anne Dorrance* |
| 11:00 AM | **Managing Insects in High-Production Soybeans: Forethought or Afterthought?** *Kevin Steffey* |
| 11:15 AM | **Future Soybean Oil and Meal Traits,** *Dennis Byron* |
| 11:35-12:00 | **Questions and Answers** |
| 12:00 NOON–1:00 PM | Lunch, on your own |

**Symposium: Managing Nutrients and Water Quality—A Balancing Act**

(Requested: 1.5 CCA credits in Soil and Water Management and 0.5 CCA credit in Nutrient Management)

Nutrients: It's the best of times, it's the worst of times. This Charles Dickens analogy is quite fitting. We face great opportunities in the fertilizer sector given the increased corn acres and higher commodity prices. We also face serious challenges with the government hypoxia report calling for significant reductions in nitrate losses from the Upper Midwest, pointing a finger at the practice of fall-applied nitrogen. The speakers will discuss the issues, the latest research regarding nutrient losses, and what you can do to balance crop production and water quality objectives. Can we take the best and worst and make it all good?

| | |
|---|---|
| 1:00 PM | **Developing Nutrient Standards for Illinois: Connecting Regulators with Researchers,** *George Czapar* |
| 1:20 PM | **Gulf Hypoxia: The Saga Continues,** *Dennis McKenna* |
| 1:40 PM | **Considerations for Managing Nitrogen When Switching from Corn/Soybean to Corn/Corn Rotations,** *T. Scott Murrell* |
| 2:05 PM | **Hypoxia and the Upper Mississippi River Basin: How Can We Reduce Nutrient Losses from Agriculture?** *Mark David* |
| 2:35 PM | **Questions and Answers** |
| 2:55–3:15 PM | Break, South Lounge |

**Symposium: Pest Resistance and Resistance Management: IPM vs. IRM**

(Requested: 2.0 CCA credits in Integrated Pest Management)

The rapid increase in the use of transgenic plants has greatly affected how producers manage a broad sprectrum of pests. Is the traditional view of IPM relevant in the current agricultural landscape of corn and soybean production? What are the current perspectives on refuge compliance and its relationship to resistance management? Will refuges be required in the future as we "integrate" multiple transgenes in corn and soybean plants? These and other questions will serve as the focus for this symposium and our panel discussion.

| | |
|---|---|
| 3:15 PM | **Mechanisms of Fungicide Resistance and a Case Study of Fungicide Resistance in Potato Production,** *Neil Gudmestad* |
| 3: 35 PM | **Glyphosate-Resistant Weeds: Yes It Can Happen, Even When You Think You Know How to Kill Weeds,** *Bill Johnson* |
| 3:55 PM | **Insecticide Resistance in Western Corn Rootworm: What Can We Learn from Previous Mistakes?** *Blair Siegfried* |
| 4:15 PM | **Refuge Compliance and Future Requirements—Panel Discussion** *Mike Gray, Moderator* |

**IRM Refuge Compliance,** *Scott Baucum*

**Increasing Corn Acres and Prophylactic use of Bt Hybrids: Implications for IPM and IRM,**
*David Onstad*

| | |
|---|---|
| 5:15–6:30 PM | IFCA-Sponsored Mixer<br>South Lounge<br>This mixer is sponsored by the Illinois Fertilizer and Chemical Association. It is intended for everyone to meet with speakers, sponsors, and committee members in an informal atmosphere. |

## Thursday Morning, January 10

**All sessions in Illini Rooms A, B, and C**

**Symposium: IPM in the Crosshairs**

(Requested: 2.0 CCA credits in Integrated Pest Management)

The demands for higher yields of corn and soybeans and the availability of extremely effective pest-control technologies have placed significant pressure on integrated pest management (IPM) practices. In fact, some people are beginning to question the relevance of some IPM principles in the context of modern agriculture. Has IPM run its course? This symposium will shed some light on the effects of modern pest management practices on agricultural ecology and the potential role of IPM in the future.

| | |
|---|---|
| 8:00 AM | **Managing the Consequences of Long-Term Weed Control,**<br>*Aaron Hager* |
| 8:20 AM | **Fungicides on Disease-Free Corn: The Case from 2007,**<br>*Emerson Nafziger* |
| 8:40 AM | **Fungicides: Do They Adversely Affect Beneficial Insect Pathogens in Multiple Cropping Systems?**<br>*David Ragsdale* |
| 9:00 AM | **How to Lose Money Despite High Crop Prices or Misuses, Misapplications, and Mistakes with Insect Thresholds,**<br>*Leon Higley* |
| 9:30 AM | **Questions and Answers** |
| 9:50–10:10 AM | Break, South Lounge |

**Symposium: High-Production Corn Management**

(Requested: 1.0 CCA credit in Crop Management and 1.0 CCA credit in Integrated Pest Management)

Corn market prices were at or near an all-time high in 2007. The cost of producing high-yielding corn is also on the rise, with a nearly bewildering array of inputs and their associated costs. Will the escalating demand for ethanol and the continuing demand for food change the way we manage the most widely grown crop in North America? This symposium will focus on managing the corn crop and its associated pests to achieve higher yields while preserving environmental integrity.

| | |
|---|---|
| 10:10 AM | **Tillage and Fertility Placement Aspects of Root Zone Optimization for Corn,**<br>*Tony Vyn* |
| 10:30 AM | **Agronomics for Corn: Have We Exhausted the Easy Options?**<br>*Roger Elmore* |
| 10:50 AM | **Corn Nematode Management,**<br>*Terry Niblack* |
| 11:10 AM | **Foliar Fungicides in Corn Production: A Look at Local and Regional Data,**<br>*Carl Bradley* |
| 11:30 AM | **The Seven Wonders of the Corn Yield World,** *Fred Below* |
| 11:55 AM | **Questions and Answers** |
| 12:15 PM | Adjourn |

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**Mike Gray**

**Sandy Osterbur**

**Kevin Steffey**

Department of Crop Sciences
University of Illinois

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# Preventing Poly Tanks from Cracking Like an Egg

*Fred Whitford*

Copyrighted Extracts. Draft Only—Do Not Copy. Will be published in 2008 as a Purdue Pesticide Programs Publication. Check www.btny.purdue/ppp for Poly Tanks on Farms and Businesses: Preventing Catastrophic Failures.

Tanks constructed from plastic are commonly used on farms and by commercial pesticide and fertilizer application businesses. These plastic tanks help to more efficiently manage the storage and transportation of water and a host of other liquids such as pesticide and fertilizer products. Plastic tanks—called polyethylene or "poly" tanks—are quite popular.

While the attributes of poly tanks are many, their use has a potentially serious drawback—at some point in time, *they will fail.* No product is designed to last forever. Poly tank useful life depends on a number of factors, including the quality and amount of poly material used to manufacture the tank, the materials stored within them, and the tanks used. The challenge is to replace the tank before it ruptures; the hard part is knowing when to do this or assessing the risk of failure. Trying to get one more year out of an "old" tank can be a serious economic and environmental mistake when its structural integrity is pushed beyond its design capability.

No one likes spending money replacing a tank that *might* still have a "few" years left in it. Realistically, there have been many instances where a poly tank that needed replacing was still being used when—"for no apparent reason"—the side walls gave way, spilling the tank's contents onto land and into water. Not only is the value of the spilled material written off as a complete loss, but the cost of cleaning up the spill can exceed the actual value of the product by thousands of dollars. In some cases, regulatory costs for restoring the environment (e.g., replacing fish) can be added to the total bill of an accidental release. Replacing used tanks should be viewed as equivalent to changing a vehicle's tires, oil, filters, and hoses; each has a limited operational life. Failing to do routine inspections and maintenance can result in expensive repairs, downtime, and aggravation.

## Tank Material Construction

Poly tanks are built with highly durable and chemical-resistant resins formulated for today's pesticides and fertilizers. Poly tanks generally are manufactured by using a process known as rotational molding. A powdered polymer compound with ultraviolet (UV) protection is poured into a two-piece mold. The mold is clamped shut and heated in a hot oven. Once completed, the mold is moved into a cooling chamber where the temperature is slowly decreased. The completed tank is then removed from the mold.

Poly tanks are molded as a single piece. A visible external seam—known as the parting line—gives the impression that two pieces are joined together at that line. The parting line is an external cosmetic artifact left over from the manufacturing process where the two halves of the mold were connected.

### SPECIFIC GRAVITY

A measure of a poly tank's ability to hold materials is based on its specific gravity rating. The specific gravity of a substance is a comparison of the chemistry (weight) of that substance to that of water. Higher specific gravity ratings mean the tank has greater ability to withstand hydrostatic stresses that can be caused by a stored liquid. Manufacturers have designed tanks with specific gravities ranging from 1.0 to 1.9 or more.

So, what do these specific ratings mean? Understanding how specific gravity is used in the evaluation of a poly tank begins with knowing that water weighs 8.334 pounds per gallon.

Water is assigned a specific gravity of 1.0, and all other specific gravities are relative to the weight of water. For instance, a poly tank with a specific gravity of 1.0 means it is designed to hold the weight of water and any other liquids weighing 8.334 pounds or less per gallon.

A poly tank rated at a 1.5 specific gravity is designed to handle the weight of a liquid product that is 1.5 times the weight of water (1.5 × 8.334). This means that a 1.5 specific gravity tank is built to withstand the internal forces of liquids weighing up to 12.5 pounds per gallon, while a 1.9 specific gravity tank can store products weighing up to 15.8 pounds per gallon.

In general, the weight of liquid fertilizers ranges from 10 to 12 pounds per gallon. Specifically, 10-34-0 liquid fertilizer weighs 11.67 pounds per gallon, while 28-0-0 liquid fertilizer weighs 10.7 pounds per gallon. Most pesticides weigh slightly below or just above the weight of a gallon of water. Thus, at a minimum, fertilizers should be stored in poly tanks with at least a 1.5 specific gravity rating. For safety reasons, a higher specific gravity tank is preferred for bulk pesticide storage, because their accidental release into the environment has significantly more negative consequences compared to those of fertilizers.

## Tank Design: Vertical Storage and Horizontal Transport

Poly tanks are divided into two distinct use designs: vertical tanks (also called stationary, upright, or "hockey puck" tanks) and horizontal tanks (side-to-side, transport, application, or leg tanks). There are significant design differences between vertical tanks and horizontal tanks that dictate how they can and, more importantly, cannot be used. Using a tank outside of its design specifications will not only void the manufacturer's warranty, but it will increase the odds of tank deterioration, tank failure, costly cleanups, and lost inventory.

Vertical tanks are flat-bottomed, cylindrical tanks designed and manufactured specifically for stationary placement on reasonably smooth, leveled surfaces. As the tank fills, the pressure of the liquid forces the wall to flex outwardly. As the tank is emptied, the walls revert back to their original shape. The pressure of the liquid is determined by the liquid's specific gravity and the fluid depth. To strengthen the tank, a manufacturer thickens the plastic where the side walls contact the tank bottom, where pressure exerted on the wall is the greatest.

Horizontal tanks are designed for placement on trucks, trailers, and field sprayers. They can also be used as stationary tanks. Pressure points on horizontal tanks are much different than those found on vertical tanks—liquid moves forward when the truck stops and backward as it accelerates, creating a surging effect that exerts the pressure on the front and back walls of the poly tank. Horizontal tanks also differ from vertical tanks in that they come with tie-down features that are more substantial in nature than vertical tanks. These tie-downs include pipe hoops and metal bands that are capable of holding the tank in place if the trailer or truck suddenly stops. In addition, the steel tubing and metal straps are used to support the sides when the tank is full.

## Six Questions to Ask When Purchasing a Poly Tank

Often the decision to purchase one tank over another is predicated on cost. You may think you are getting a great deal on a less expensive tank, because you generally assume there can be little or no difference between two seemingly identical tanks. But without information such as its specific gravity rating and tank warranties, the less expensive tank may not actually be a better deal. Comparing tanks with similar specifications is the only way to accurately price tanks. Consider the following six questions when purchasing a poly tank.

**Question 1. What size poly tank do I need to purchase?**

**Question 2. How will I use the poly tank?**

**Question 3. What specific gravity should I select?**

**Question 4. What level of service do I expect?**

**Question 5. How much does the poly tank really cost?**

**Question 6. How does the cost of the poly tank compare with other materials used to manufacture tanks?**

## Tank Longevity: How Long Can I Expect the Tank to Last?

Most farmers and business owners expect to use their storage, transport, and application tanks well beyond the 3 to 5 year manufacturer's warranty. This obviously brings up the question: "How old is too old for a tank?" or "How long will a tank last?" No one can predict how long any given tank will last. There is not, nor has there ever been, a set rule that says a tank needs to be taken out of service at a certain age. It's an impossible question to answer with any confidence or accuracy! All tank products fail at some time or another.

**TABLE 1 • Factors that shorten and extend the life of a poly tank.**

| Contributing factor | Shortens life of tank | Extends life of tank |
|---|---|---|
| tank specific gravity rating | lower specific gravity rating | higher specific gravity rating |
| filling/refilling | frequent | infrequent |
| exposure to sunlight | constant exposure | covered and sheltered |
| operation | transportation | stationary |
| liquid type | reacts with tank | nonreactive (e.g., water) |

## Factors That Influence Longevity

A number of factors influence how long a tank remains serviceable. The factors shown in Table 1 all contribute to answering the question of how long a tank will last. However, the exact number of useable years varies highly from location to location. The only true way to assess the deterioration and damage of a tank is to do routine inspections and testing in the fall and spring. The surest way to avoid tank failures is to replace the poly tank when the warranty expires. Others will base their decision to replace a tank on the findings from an inspection and testing of the tank.

## Fall and Spring Tank Inspections

Whether it's an 8-year-old application tank or one that you've used for 20 years, the only way to know whether a tank is structurally sound for use is to perform an inspection in the fall at the end of the season and in the spring prior to first fill for spring planting. Inspections at the end of the application season provide ample time to purchase a new tank if the old one is found defective or deemed unreliable. The inspection in the spring prior to filling provides reassurance that the tanks can safely store or transport the anticipated fertilizers and/or pesticides that will be placed into them.

It can be difficult to visually separate a good tank from a bad tank. Two simple inspection techniques—marking with a water-soluble pen and the "baseball bat test"—can pinpoint weakened walls and stressed areas around the fittings.

### MARKING THE TANK WITH A WATER-SOLUBLE BLACK MARKER

The water-soluble marker can be used during inspections to highlight cracks and scratches on and in the tank. More importantly, this inspection technique can be used to pinpoint internal lines known as "crazing" within the resin. Crazing can be caused by physical damage or be the starting signs of UV damage. UV crazing is hard-to-see damage formed in areas where the tank receives maximum sunlight exposure or stress. These lines may be made more visible to the eye with the marker coloring. Crazing or excessive surface oxidation is one of the first signs of deterioration. Tanks with crazing should be checked often, and consideration should be given to putting the tank to other uses (e.g., water tank).

Rub the marker over a 6- by 6-inch section around the sides of the tank exposed to sun, on its top, and around any fitting. Quickly rub off the ink with a dry cloth or paper towel. What is left behind is the ink that has penetrated into the surface of the tank.

In many cases, rubbing the ink off reveals no obvious signs of crazing or cracking. These tanks are in all likelihood good for another season of use. If the ink reveals evidence of cracking where the lines go in both directions, this represents classic UV radiation damage. An indication of advanced deterioration to the plastic is when a checkered appearance, or "dry rot," look is seen on the tank's walls. Tanks showing this type of cracking have lost much of their plasticity, and they should be replaced or removed from service for chemical storage or transportation.

The first signs of UV damage on a tank—where the lines are parallel to each other but not connected—are also an indication of the beginnings of deterioration. These cracks will need to be watched more closely during the upcoming years. The only exception is that tanks with parallel lines in the plastic around the tank fittings should be immediately replaced or used for water.

### HITTING AN EMPTY TANK WITH A BASEBALL BAT

Empty tanks showing UV cracking can be further evaluated by striking the affected area with a baseball bat. (It seems that most people are afraid to hit their tank with a bat for fear that they might break it!) This test reveals the symptoms of UV breakdown in the plastic. If the hit breaks the tank, it should not be in service. It may seem too aggressive a test,

but it is a better option than a tank breaking that is filled with product.

A good tank has flexibility to bend outward as the tank is filled and inward as the tank is emptied. Tanks that are brittle (excessive and advanced cracking) lose their ability to flex or rebound. To test the brittleness of the tank, take a baseball bat, and, with a solid swing, hit the empty tank where signs of cracking have been discovered by the water-soluble pen inspection. Hit the tank on the top and along the sides that receive most of the sunlight. Check the tank for signs of breaking after hitting it with a bat. Using this method, it is impossible to crack a tank that still retains resiliency—and, thus, strength—in its resin. Obviously, if the tank cracks or breaks open after being hit by a bat, the tank will have to be replaced.

## Conclusions

High-density polyethylene tanks have been successfully used for years by growers and commercial pesticide application businesses. Polyethylene tanks offer many advantages for the producer and business owner. Lower cost compared with other tanks (such as stainless steel and fiberglass), ease of movement when empty, and rust resistance are just three of the advantages. Polyethylene tanks are low maintenance and are a relatively reliable means of storing and transporting liquids.

While the benefits of poly tank ownership are proven and well established, the risk of tank failure is real. Like any piece of equipment, poly tanks need to be maintained and inspected so that the benefits of use outweigh the risk of tank failures and subsequent product releases.

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# Soybean Management for Maximum Yields AND Profits

*Seth Naeve*

# Managing Soybean Cyst Nematode for Maximum Soybean Productivity

*Gregory L. Tylka*

The soybean cyst nematode (SCN), *Heterodera glycines*, has plagued midwestern soybean production for several decades. It continues to be a serious, yield-limiting pest of soybeans throughout the Midwest, causing yield losses directly as well as indirectly by intensifying other serious soybean diseases.

SCN is widely distributed throughout the most soybean-producing states in the Midwest. It was found in 74% of Iowa fields and 82% of Illinois fields in a random survey in the mid-1990s (Workneh et al. 1999). The nematode has excellent long-term survival, and its population densities build up each year that susceptible soybeans are grown, regardless of the rainfall and temperature that occur during the growing season. Up to 40% yield loss can occur without the appearance of any aboveground symptoms (Wang et al. 2003).

The SCN life cycle begins when the juvenile worm hatches from the egg (Figure 1). This juvenile cannot develop further until it enters a soybean root and successfully establishes and maintains a feeding site composed of living, but drastically altered, soybean root cells. With adequate nutrition, the hatched SCN juvenile passes through two additional juvenile stages while feeding inside the root before becoming an adult. As SCN females develop, the juvenile stages swell, eventually becoming round or lemon shaped.

The fully formed SCN female is as large as the period at the end of this sentence. The female's size causes it to rupture through and be exposed on the surface of the root. Development of SCN males is very similar to that of females until just before adulthood. At that time, the swollen male juveniles revert back into a worm shape, stop feeding, and exit the root to migrate through the soil. Adult males in the soil are attracted to adult females on the root surface by compounds produced by the SCN female, and mating occurs on the root surface.

After mating, the SCN females begin to produce eggs. The SCN female first produces approximately 50 eggs outside the body in a gelatinous material to form an egg mass. Once the egg-mass eggs are deposited, additional eggs begin to be retained inside the SCN female body cavity. There will be up to 200 or more eggs formed within the SCN female body cavity. Eventually, the SCN female dies, and her body wall turns tough and leathery to form a protective covering of the eggs called the cyst.

For all practical purposes, SCN can never be eliminated from a field once it is present. However, there are things that can be done to manage the nematode in order to maximize soybean yields and minimize reproduction of the nema-

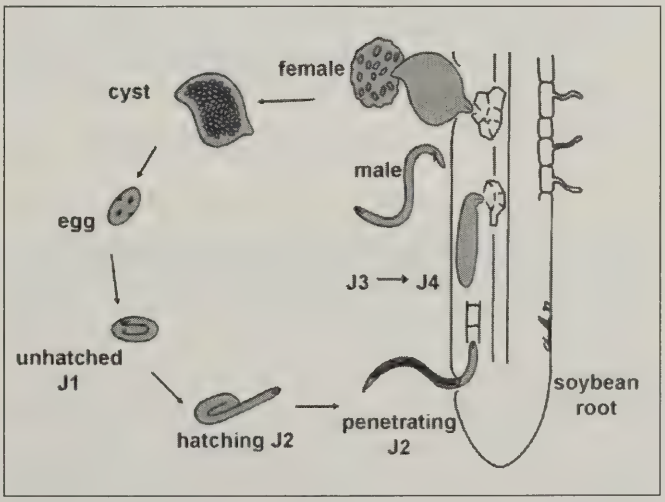


**FIGURE 1 • Diagram of the life cycle of the soybean cyst nematode. J1 = first-stage juvenile, J2 = second-stage juvenile, J3 = third-stage juvenile, J4 = fourth-stage juvenile. Not all of the life stages illustrated are drawn to the same scale.**

tode. Effective management of SCN involves an integrated approach of scouting for early detection of infestations, followed by proper use of resistant soybean varieties in rotation with nonhost crops in infested fields. Also, a few soil-applied nematicides are available for management of the nematode. The economics of fieldwide application of such chemicals need to be considered before utilizing this management strategy.

## SCN-Resistant Soybean Varieties

SCN-resistant soybean varieties are not immune; they can allow up to 10% SCN reproduction. But allowing only 10% reproduction means the varieties are providing 90% control. So, SCN-resistant varieties not only produce greater yields than susceptible varieties in SCN-infested fields, but they also prevent large increases in SCN population densities. The suppression of SCN reproduction afforded by SCN-resistant varieties allows for profitable, long-term production of soybeans in SCN-infested fields.

The Iowa State University (ISU) SCN-Resistant Soybean Variety Trial Program annually evaluates the yield and SCN control provided by a large number of SCN-resistant soybean varieties available to Iowa growers in field experiments conducted at various locations throughout the state. Varieties are grown in replicated plots at each experimental location. Soil samples are collected from each four-row plot (ten soil cores from the center two rows of each plot) at the time of planting and analyzed to verify the presence of SCN in every plot. At harvest time, another soil sample is collected from each four-row plot, and SCN population densities are determined to assess how well the SCN population reproduced on the soybean variety grown in each plot. Commonly grown, SCN-susceptible varieties are included in each experiment.

The average yield of the numerous SCN-resistant soybean varieties in the Melrose and Churdan, Iowa, locations of the ISU SCN-Resistant Variety Trial Program compared to the four SCN-susceptible varieties included in each trial in 2006 are shown in Table 1. Also presented in the table are average end-of-season SCN population densities in plots planted with the SCN-resistant and SCN-susceptible varieties at these locations in 2006.

At the Melrose location, SCN-resistant soybeans yielded, on average, 4 to 5 bushels per acre more than SCN-susceptible soybean varieties, and there was 6 to 13 times more SCN reproduction on the susceptible varieties than on the resistant varieties. At Churdan, SCN-resistant soybeans yielded, on average, 16 to 17 bushels per acre more than SCN-susceptible soybean varieties, and the susceptible varieties allowed 8 to 14 times more SCN reproduction than the resistant varieties. These data clearly illustrate that SCN-resistant soybean varieties pay dividends twice—in the form of increased yields and in control of SCN population densities.

At the time that these conference proceedings were compiled, final SCN egg population density data were not yet available for the 2007 ISU SCN-Resistant Soybean Variety Trial Program locations. However, the summary yield data from 2007 for the SCN-resistant soybean varieties and the susceptible varieties, shown in Table 2, again illustrate the increased yield of SCN-resistant soybean varieties relative to susceptible soybean varieties in SCN-infested fields. In most of these variety trial locations in 2007, the SCN-resistant varieties, as a group, produced greater yields than the widely grown, SCN-susceptible soybean varieties. The smallest positive yield difference between resistant and susceptible varieties in 2007 was 1.5 bushels per acre at the Council Bluffs location, in southwest Iowa, where the initial SCN population density was 515 eggs per 100 cc of soil. And the

**TABLE 1 • Average yield and end-of-season SCN population densities of SCN-resistant and SCN-susceptible varieties at the Melrose and Churdan locations of the ISU SCN-Resistant Soybean Variety Trial Program in 2006.**

| Location and variety type | Yield (bu/A) | | Final SCN population densities (eggs per 100 cc soil) | |
|---|---|---|---|---|
| | Resistant varieties | Susceptible varieties | Resistant varieties | Susceptible varieties |
| Churdan | | | | |
| Roundup Ready® | 55.7 | 40.5 | 2,460 | 19,594 |
| Conventional | 52.2 | 34.6 | 1,629 | 22,568 |
| Melrose | | | | |
| Roundup Ready® | 52.1 | 46.8 | 1,762 | 11,444 |
| Conventional | 52.2 | 48.2 | 936 | 13,168 |

**TABLE 2 • Average yield of SCN-resistant and SCN-susceptible varieties at several locations of the ISU SCN-Resistant Soybean Variety Trial Program in 2007.**

| Location | Initial SCN population density (eggs/100 cc) | Yield (bu/A) Resistant varieties | Susceptible varieties | Yield benefit (bu/A) |
|---|---|---|---|---|
| Northern Iowa District | | | | |
| Albert City | 3,353 | 63.0 | 51.8 | 11.2 |
| Manchester | 301 | 58.9 | 60.2 | 1.3 |
| Vincent | 4,001 | 45.4 | 31.2 | 14.2 |
| Central Iowa District | | | | |
| Cambridge | 3,156 | 59.3 | 55.1 | 4.2 |
| Farnhamville | 5,461 | 54.8 | 48.0 | 6.8 |
| Urbana | 5,369 | 59.5 | 52.6 | 6.9 |
| Southern Iowa District | | | | |
| Council Bluffs | 515 | 67.4 | 65.9 | 1.5 |
| Crawfordsville | 2,329 | 57.2 | 59.8 | –2.6 |
| Melrose | 5,242 | 60.9 | 50.8 | 10.1 |

greatest yield difference, 14.2 bushels per acre, occurred at the Vincent location, in north-central Iowa, where the initial SCN population density was 4,001 eggs per 100 cc of soil.

In two of the ISU SCN-Resistant Soybean Variety Trial Program locations in 2007, the SCN-susceptible varieties yielded more than the SCN-resistant varieties as a group (Table 2). This occurred at Manchester, in northeast Iowa, where the initial SCN population density was very low (301 eggs per 100 cc of soil) and in Crawfordsville in southeast Iowa, where there was an initial SCN population density of 2,329 eggs per 100 cc of soil. Complete yield and SCN population density data from the 2007 ISU SCN-Resistant Soybean Variety Trial Program experiments will be available online in early 2008 at www.isuscntrials.info.

## SCN Populations That Can Reproduce on PI 88788 Resistance

Surveys have been conducted and are ongoing in several Midwest states to determine how well the SCN populations can reproduce on the various sources of SCN resistance. In 1991, Sikora and Noel reported that 34% (15 of 44) of surveyed SCN populations in Illinois had >10% reproduction on PI 88788. But 65% of 260 SCN populations from Illinois surveyed in 2005 had >10% reproduction on PI 88788 (T.L. Niblack, personal communication). Niblack et al. (2003) reported that nearly 60% of 183 SCN populations obtained through a random survey of Missouri in 1998 had >10% reproduction on PI 88788, but Mitchum et al. (2007) reported that 78% of 45 samples collected from Missouri in 2005 had >10% reproduction on PI 88788.

Many Iowa SCN populations are able to reproduce greater than 10% on PI 88788, too. In fact, the SCN populations in about half of the ISU SCN-Resistant Soybean Variety Trial Program locations from 2005 to 2007 had >10% reproduction on PI 88788. And, although almost all of the SCN-resistant varieties evaluated in the ISU SCN-Resistant Soybean Variety Trial Program have SCN resistance genes from PI 88788, most of the resistant varieties usually yielded greater than the susceptible varieties at these locations.

## Use of Nonhost Crops

There are many crops on which SCN is unable to feed. These are called nonhost crops. Corn, most small grains, and some legumes are nonhosts for SCN. The greatest decrease in SCN population densities may occur during the first year a nonhost crop is grown after a soybean crop. In general, growing corn for 1 year after a soybean crop in Iowa will reduce the SCN population density from as little as a few percent to as much as 50%. It is not known why there is so much variation in the effect of corn on SCN population densities from year to year. SCN population densities decline less in the second year of corn after a soybean crop, and even less in the third year of corn in Iowa.

## Summary

SCN is a very damaging, long-lived, and widespread pest of soybeans. Successful, long-term management of SCN requires growing SCN-resistant soybean varieties in rotation with the nonhost crop corn.

SCN-resistant soybean varieties are an effective and affordable tool to manage SCN, providing greater yields than susceptible varieties and preventing increases in SCN population densities. Almost all SCN-resistant soybean varieties available to Iowa and Illinois growers possess SCN-resistance genes from PI 88788 (Tylka 2006; Shier 2007), and it is no longer uncommon for SCN populations to have 10% or greater reproduction on PI 88788. But SCN-resistant varieties with PI 88788 as the source of resistance continue to yield better than susceptible soybean varieties and also continue to prevent increases in SCN population densities throughout the growing season. So, growing resistant varieties is still an effective way to manage SCN.

SCN-resistant varieties with different sources of resistance should be rotated whenever possible to reduce selection of SCN populations that can reproduce on SCN-resistant varieties. And growers who have managed SCN with resistant soybean varieties for several years should collect soil samples from fields and determine SCN population densities to assess whether nematode population densities are increasing.

## References


Mitchum, M.G., J.A. Wrather, R.D. Heinz, J.G. Shannon, and G. Danekas. 2007. Variability in distribution and virulence phenotypes of *Heterodera glycines* in Missouri during 2005. *Plant Disease* 91:1473–1476.

Niblack, T.L., J.A. Wrather, R.D. Heinz, and P.A. Donald. 2003. Distribution and virulence phenotypes of *Heterodera glycines* in Missouri. *Plant Disease* 87:929–932.

Shier, M. 2007. *Soybean Varieties with Soybean Cyst Nematode Resistance.* University of Illinois Extension publication. 50 pp. www.ag.uiuc.edu/~wardt/cover.htm.

Sikora, E.J., and G.R. Noel. 1991. Distribution of *Heterodera glycines* races in Illinois. *Supplement to the Journal of Nematology* 23:624-628.

Tylka, G.L. 2006. Soybean Cyst Nematode-Resistant Soybean Varieties for Iowa. Iowa State University Cooperative Extension Service, Publication Pm-1649, 26 pp.

Wang, J., T.L. Niblack, J.A. Tremaine, W.J. Wiebold, G.L. Tylka, C.C. Marett, G.R. Noel, O. Myers, and M.E. Schmidt. 2003. Soybean cyst nematode reduces soybean yield without causing obvious aboveground symptoms. *Plant Disease* 87:623–628.

Workneh, F., G.L. Tylka, X.B. Yang, J. Faghihi, and J.M. Ferris. 1999. Assessment of soybean brown stem rot, *Phytophthora sojae*, and *Heterodera glycines* in the north central United States using area-frame sampling: Prevalence and effects of tillage. *Phytopathology* 89:204–211.

# Foliar Fungicides and Fungicide Seed Treatments: Getting That Return on Investment

*Anne Dorrance, Dennis Mills, Bruce Eisley, Dave Mangione, John Yost, Gene McClure, Roger Bender, Alan Sundermeier, Dusty Sonnenberg, Ron Hammond, Christian Cruz, and Kirk D. Broders*

Fungicide use on soybeans, both from seed treatment and foliar applications, has been increasing over the past five years. These added inputs can cost from $4 to $28 per acre, depending on the fungicide active ingredient and application costs. We evaluated several different compounds both in on-farm studies and research plot studies to determine what conditions favor the greatest return. This article is separated into two parts: Foliar Fungicides and Seed Treatment Fungicides.

## Foliar Fungicides

The use of foliar fungicides is a routine practice in the southern U.S. (Tennessee, Arkansas, Georgia, Mississippi, Alabama, and Louisiana) to manage frogeye leaf spot, purple leaf stain, southern stem canker, and aerial blight. In the north-central U.S., none of these diseases are present at economic levels with one exception, frogeye leaf spot during the 2006 and 2007 production season in Ohio. The most common foliar diseases in Ohio are brown spot and downy mildew. Soybean rust has not been found (infected leaves with sporulating pustules) to impact the crop in Ohio.

We have taken three approaches to evaluate the impact of foliar fungicides on soybeans in Ohio:

1. the combination of fungicide and insecticides in on-farm trials
2. the impact of strobilurin and triazole fungicides on brown spot
3. the effects of brown spot on soybean yield

The primary foliar pathogen in Ohio is brown spot caused by *Septoria glycines*. This is believed to be a minor pathogen because it infects older leaves in the lower canopy and rarely moves up into the midcanopy until R7–R8. The following is a brief summary of each of these studies.

### EVALUATION OF THE COMBINATION OF FUNGICIDES AND INSECTICIDES IN ON-FARM TRIALS

For these trials, large fields (50 acres or more) were selected. Producers and county Extension educators applied treatments using their own equipment and harvested the plots. The study was treated in a randomized block design with three to five replications, depending on the size of the field. Data were collected 3 weeks after the last application on the incidence and severity of brown spot and other foliar diseases, if present, and aphids. During 2004 and 2005, the treatments were Quadris (6.4 fl oz/A), Warrior (3.2 fl oz/A), Quadris plus Warrior (6.4 and 3.2 fl oz/A, respectively), and a nontreated strip. During 2006, the treatments were Headline (6.0 fl oz/A), Folicur (4.0 fl oz/A), Headline plus Folicur (4.7 and 3.2 fl oz/A, respectively), and a nontreated control strip. During 2007, the treatments were Headline (6.0 fl oz/A), Domark (4.0 fl oz/A), and a nontreated strip.

There was no significant difference in the levels of brown spot at any of the locations during the 4 years of this study. During 2004, 2006, and 2007, aphids were not found in any of the locations, but, during 2005, high levels of aphids were identified in some of the locations. Frogeye leaf spot was present in three locations during 2006 and none in 2007.

These studies found no consistent advantage in the application of Quadris, Headline, or Domark (Tables 1–4). Across all studies, Quadris and Headline contributed to an increase in yield 50% of the time, with an average increase of 3.5 bushels per acre. Warrior provided excellent control of soybean aphids; however, timing of applications was better at the

recommended time (250 aphids per plant) compared to applications made at the R3 growth stage with lower aphid populations.

In two fields, aphid populations were low at the R3 growth stage, and the fields required a second application or did not get the huge benefit of the insecticide.

## STROBILURIN AND TRIAZOLE CONTROL OF BROWN SPOT

During 2006, four soybean varieties were planted at the OARDC Northwestern and Western research stations. This study consisted of Headline, Folicur, Headline plus Folicur, Quadris applied at R3 and R5 growth stages, and two nontreated plots. The study was arranged in a split-plot design, where the varieties were replicated first, then, for each variety, the fungicide treatments were randomized.

In both locations of this study, fungicide treatments increased yields, albeit at 3.4 and 6.8 bushels at Northwestern and Western from one untreated plot and 1.5 and 4.3 from the second untreated plot at the same locations (Table 5).

## EFFECTS OF BROWN SPOT ON YIELD

For the final study, we assessed disease severity levels of brown spot on four soybean varieties treated with Echo (chlorothalonil) at two locations. This study was arranged in a split-plot design, with the varieties replicated first and chlorothalonil treatments as the subplots. (Note: This is not a labeled use of chlorothalonil; this study was done to determine

**TABLE 1 • Comparison of Quadris and Warrior to the nontreated control during 2004.** There were no aphids and very low levels of foliar-feeding insects. Only at the Hardin and Wood locations were the treatments significantly better than the control, and, in these situations, the increase over the nontreated controls was 5 and 3.5 bushels per acre.

| 2004 location | Quadris + Warrior, yield difference from nontreated (bu/A) |
|---|---|
| Henry/Beck | –2.0 |
| Henry/Fritz | –0.6 |
| Hardin/Shick | 5.4* |
| Hancock/Wilson | 4.1 |
| Woods/Keys | 3.1* |
| Fulton/Shininger | –4.1 |
| Miami/Worthington | 0.4 |
| Miami/Hodge | 2.2 |
| Shelby/Joslin | 3.9 |
| Morrow/Weiler | –0.6 |
| Wayne/OARDC | –1.1 |
| Wooster/OARDC | 1.9 |

* Denotes that yield was significantly different than that of the nontreated controls for that location ($P = 0.05$).

**TABLE 2 • Five of the locations with very low or no aphid pressure during 2005.** For these fields, Warrior was significantly better than the nontreated controls in Hardin and Licking counties. Both locations had a high amount of feeding from grasshoppers and Japanese beetles.

| | Yield difference from nontreated (bu/A) | | |
|---|---|---|---|
| 2005 location | Quadris | Warrior | Quadris + Warrior |
| Fayette | –0.2 | 4.6 | 2.2 |
| Hancock | –0.6 | 0.5 | 5.5 |
| Hardin | 1.2 | 4.5 | 6.0 |
| Licking | 4.2 | 3.0 | 5.1 |
| Morrow | 2.2 | 4.4 | 4.8 |

**TABLE 3 • Seven of the locations had very high aphid populations.** For all but one location, treatments were significantly better than the controls. In these cases, Warrior alone was providing the protection.

| | Yield difference from nontreated (bu/A) | | |
|---|---|---|---|
| 2005 location | Quadris | Warrior | Quadris + Warrior |
| Fulton | 1.0 | 13.0 | 12.5 |
| Henry/B | 3.1 | 7.0 | 7.3 |
| Henry/F | 3.1 | 13.6 | 15.3 |
| Ottawa | –1.5 | 8.0 | 8.1 |
| Shelby/J | 0.1 | 3.8 | 2.6 |
| Wood/M | 0.2 | 0.9 | 4.3 |
| Wood/S | 5.1 | 15.2 | 16.2 |

**TABLE 4 • Difference from nontreated control during 2006 and 2007 in on-farm evaluations.** Three locations during 2006 had 0.5% to 3.0% leaf area affected by *Cercospora sojina*, which causes frogeye leaf spot during 2006, but no fields were heavily impacted during 2007.

| | 2006 | | | 2007 | |
|---|---|---|---|---|---|
| Location | Headline | Folicur | Headline + Folicur | Headline | Domark |
| Ross | 8.6 | 3.6 | 6.8 | 3.6 | 2.5 |
| Ross | — | — | — | 1.3 | –1.4 |
| Wood | 0.2 | 0.3 | 1.1 | 6.3 | 5.3 |
| Fayette | 4.3 | 1.4 | 9.8 | | |
| Hardin | 4.8 | –0.2 | 1.6 | 0.7 | –0.6 |
| Henry | 0.3 | 1.2 | 1.7 | | |
| Shelby | 3.7 | 3.0 | 2.2 | | |
| Overall | 3.5 | 1.5 | 4.1 | 3.2 | 1.7 |

tial but highly variable, as in Ross County during 2006.

We demonstrated that many of these fungicide applications reduce the incidence and severity of foliar diseases and we demonstrated efficacy on some of the minor foliar pathogens found in Ohio. However, the final question is, are these applications economically viable in today's volatile soybean price market?

Across all studies, on average, we gained 3 bushels per acre. For application to be economically viable, soybean price must be $8 or higher and the gain must be consistently greater than 3 bushels per acre. Under Ohio conditions, this occurred only 20% to 50% of the time. The best economic use of fungicides was when frogeye leaf spot was prevalent at the R3 growth stage on highly susceptible soybean varieties.

## Fungicide Seed Treatments

the effects of brown spot). Echo was applied, almost weekly, beginning at V1 (first fully expanded trifoliate) until R6 (full seed). The total number of Echo applications in this study ranged from 0 to 10. Again, this is not a labeled use of chlorothalonil and is the type of study suited only for research farms.

In this study, disease severity was reduced with the weekly applications of Echo and yield was increased (Table 6). Final yields were 4 and 2.8 bushels per acre over the nontreated control at Western and Northwestern Agricultural research stations, respectively. From this first year, brown spot does contribute to yield loss, at least at low levels.

In these trials, fungicides, in the majority of cases, increased yield. Sometimes the results were difficult to measure. In other cases, the increased yield was substan-

**TABLE 5 • There was a significant difference among the fungicide treatments compared to one of the untreated plots**—for the level of brown spot at the NWB location only, Headline, Folicur, Headline plus Folicur, Quadris, and Headline at R3 followed by Folicur at R5. Disease levels were much lower at the Western research station and were not significantly different.

| | Percent leaf area affected @ R5 | | Yield, bu/A | |
|---|---|---|---|---|
| Treatment | Northwestern | Western | Northwestern | Western |
| Nontreated | 19 | 11 | 46.2 c | 61.9 d |
| Headline @ R3 | 18 | 7 | 49.6 a | 66.0 a-c |
| Headline @ R5 | 25 | 14 | 48.9 a | 65.4 a-d |
| Headline + Folicur @ R3 | 14 | 8 | 48.6 ab | 65.3 a-d |
| Headline + Folicur @ R5 | 29 | 10 | 48.3 abc | 68.7 a |
| Folicur @ R3 | 17 | 7 | 46.5 bc | 66.1 ab |
| Folicur @ R5 | 27 | 11 | 47.8 abc | 65.1 a-d |
| Nontreated | 26 | 15 | 48.1 abc | 64.3 b-d |
| Quadris @ R3 | 16 | 12 | 49.5 a | 62.0 cd |
| Headline @ R3 + Folicur @ R5 | 17 | 13 | 46.5 bc | 65.7 a-d |
| Means | 21.2 | 10.6 | 48 | 65 |

Means followed by the same letter are not significantly different ($P = 0.05$).

**TABLE 6 • Echo reduced the level and severity of brown spot at both locations and increased yield by 4 and 2.8 bushels per acre at the Western and Northwestern research stations, respectively.** Brown spot is a minor foliar disease of soybean in Ohio.

| | Percent leaf area affected | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Number of sprays** | **10** | **9** | **8** | **7** | **6** | **5** | **4** | **3** | **2** |
| Western Station | 0.08 | 0.42 | 0.0 | 0.83 | 0.83 | 12.6 | 5.75 | 9.58 | 10.08 |
| Northwestern Station | 5.8 | 5.4 | 5.4 | 5.4 | 7.5 | 9.6 | 18.3 | 18.8 | 26.7 |
| | **Yield difference from nontreated, bu/A** | | | | | | | | |
| Western Station | 5.6 | 4.6 | 4.5 | 3.2 | 9.8 | 0.5 | 2.2 | 1.8 | 3.1 |
| Northwestern Station | 2 | 3.8 | 4.1 | 3.7 | 1.9 | 1.8 | 3.7 | 0.9 | 0.3 |

Many production fields along the Great Lakes and rivers have higher clay contents. Areas of the Midwest that were once covered with swampland are now highly productive fields. However, these same fields are prone to several soilborne pathogens including *Phytophthora sojae*, *Pythium*, and *Fusarium*.

Several years ago, we demonstrated that to manage *P. sojae*, a high rate of mefenoxam or metalaxyl (ApronXL and AllegianceFL) was required for efficacy. Despite the higher rates of seed treatment, some producers were still experiencing stand loss without excessive flooding. In addition, establishment of corn in some fields was becoming an annual problem even with the use of seed treatments. We have begun a series of studies that evaluate which seed and seedling pathogens are predominant in Ohio and which seed treatment fungicides are most effective against these corn and soybean pathogens.

Seeds and seedlings with symptoms of early-season dampingoff were collected from 42 locations throughout the state from problem fields. From these samples, 11 species and two distinct morphological groups of *Pythium* were identified, of which six species were moderately to highly pathogenic on corn seeds and nine species were highly pathogenic on soybean seeds.

Our most important finding in this study was that mefenoxam, azoxystrobin, trifloxystrobin, or captan, when used individually, may not inhibit all pathogenic species of *Pythium* found in Ohio soils. Thus, reliance on only one active ingredient may have contributed to some of the stand establishment problems.

These studies were all from problem fields. Our next priority is to determine how widespread these problems are in the state and then to develop some recommendations on which fungicide combinations will be able to control the majority of Ohio's *Pythium* populations.

## Acknowledgments

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# Managing Insects in High-Production Soybeans: Forethought or Afterthought?

*Kevin L. Steffey*

Crop production practices, technologies, and expectations have changed significantly during the past 10 years, reshaping agriculture as we used to know it. These changes are particularly obvious in the Midwest, where most of the arable land is devoted to production of corn and soybeans.

The demand for corn is at an all-time high, so more acres are being dedicated to its production. In large part, the increase in acreage of corn will occur at the expense of acreage dedicated to soybean production. Consequently, soybean producers will expect higher yields per acre, counting on improved soybean genetics, different production practices, and new pest management technologies and practices to help them meet their expectations. Companies that supply seed and agricultural chemicals to soybean producers anticipated the producers' expectations and have developed products that offer solutions for yield-limiting factors such as insects and plant diseases.

Where does insect management fit into the expectations for higher yields of soybeans? Do our expectations for higher yields include regular, possibly annual, expenditures for insect control? What will befall the ecology of soybean fields if regular use of insecticides becomes routine?

These questions cannot be addressed with simple responses, and many related questions remain to be asked and answered. So, the objective of this paper is to frame the discussion regarding the future of insect management in soybeans. Ultimately, all of the opportunities and challenges will be sorted out in the fields.

## Soybean Insect Management, 1960s Through 1990s

Before 2000, soybean producers in the Midwest had very few recurring concerns about insect management. From the 1960s through the 1990s, insect and mite pests of soybeans caused widespread economic losses infrequently, so average annual expenditures for insect management for the vast majority of producers were very low to nil. Only relatively uncommon outbreaks of insect or mite pests (e.g., the outbreak of twospotted spider mites in 1988) required conspicuous use of insecticides. Most insect pests of soybean during this time period were classified as either subeconomic or occasional,[1] so most producers were content to rely on occasional scouting trips and knowledge of economic thresholds for making informed insect management decisions.

Scouting and economic thresholds were outgrowths of the emphasis on integrated pest management (IPM) in the 1970s and 1980s and became the foundation of insect management programs. Soybean producers in particular understood the concept that an insecticide was unnecessary unless densities of insects were large enough to cause economic loss (Pedigo and Rice 2006a).

[1] The average population density of a subeconomic pest does not reach the economic injury level (roughly, cost of control = value of loss). The average population density of an occasional pest exceeds the economic injury level occasionally, sporadically, and usually unpredictably.

Insecticide use to prevent insect injury to soybeans was virtually unheard of because insect pests threatened soybean yields so infrequently. Because soybean plants have an exceptional ability to tolerate and compensate for insect injury, entomology researchers were able to determine simple economic thresholds based on percentage defoliation caused by insects. These percentage defoliation thresholds[2] were associated with most of the "major" soybean insect pests at the time (e.g., bean leaf beetle, Japanese beetle, grasshoppers, green cloverworm), and they served us remarkably well as insect management guidelines. Making insect management decisions was simple and relatively easy—semi-regular scouting trips, a sweep net, a drop cloth, the ability to count, the ability to estimate percentage defoliation, an array of effective insecticides (carbamates, organophosphates, pyrethroids), and an applicator, if needed, were all the "tools" necessary to deal with occasional insect problems. IPM principles for soybean insect management were relatively easy to accept during the 1960s through the 1990s.

## Soybean Insect Management, 2000 Through 2007

During the 1990s, leaders in soybean production strove to narrow the gap between attainable yields and yields usually harvested by producers. Breaking through the soybean yield barrier and improving oil and protein content became objectives for soybean producers who had higher expectations for soybean production. Expectations for higher soybean yields were addressed with improved genetics, biotechnology, and improved production practices. Concomitant with the emphasis on higher yields of soybeans were some significant events that have changed soybean producers' attitudes about pest management:

- 2000—elevated concerns about bean leaf beetles transmitting bean pod mottle virus
- 2000—discovery of the soybean aphid in North America
- 2003 to 2005—registration of seed-applied neonicotinoid insecticides (Cruiser, Gaucho) for control of soybean insects
- 2004—Asian soybean rust confirmed in the United States, followed by numerous registrations of fungicides for use in soybeans

These events have focused considerable attention on pest management in soybeans and have resulted in promotion of practices that may or may not be necessary for obtaining higher soybean yields. Promotions of "progressive approaches," "innovative products," and "plant health" encourage soybean producers to spend money on fungicides and insecticides to maximize yields. Consequently, insect management has become a forethought (suggesting a preventive approach) rather than an afterthought (suggesting a therapeutic approach)—quite a change from the attitude in previous decades. Although there is nothing inherently wrong with prevention of a known insect problem, widespread "prevention" of an insect problem that does not exist and may not develop is not cost effective and may have unintended consequences.

Many soybean producers use relatively simple economic metrics when considering the use of a pest control product (i.e., the economic return is equal to or greater than the economic investment). Promotions of "plant health" products almost always indicate yield gains that will more than offset the cost of the products, especially considering the recent, significant increase in the value of soybeans. A soybean producer needs to gain only 1 bushel (or less) per acre of $10 soybeans to offset the cost of a typical insecticide application. If the goal is maximization of soybean yield, applying pesticides will probably help producers achieve the goal, at least for the short term. Planting soybean seed treated with fungicides and insecticides and application of tank mixes of pesticides (e.g., fungicide + insecticide, herbicide + insecticide) in some fields for a few years probably will bolster soybean yields. The "instinct to capitalize on the opportunity for financial reward" (a quotation from a friend) currently is very strong.

In keeping with simple economic metrics, however, it is necessary to call attention to the fact that the cost of producing soybeans also is increasing. In a recent report, Schnitkey and Lattz (2007) revealed that non-land costs for producing soybeans are projected to increase in 2008, averaging around $220 per acre. With land costs included, producing soybeans on many farms in Illinois will cost $400 to $450 per acre. Given these costs, break-even revenues will be above $8 per bushel for soybeans in 2008. Consequently, spending money on pesticides for presumed yield benefits represents an economic risk.

[2] Roughly 30% defoliation before bloom and 20% defoliation from bloom to pod fill.

## Soybean Insect Management, 2008 and Beyond: Opportunities and Challenges

At least for the short term, it is likely that reliance on inputs for pest management will prevail over the decision-making requirements associated with IPM, which is information intensive. Short-term cost/benefit ratios are relatively easy to calculate; the costs associated with misuse or overuse of pesticides are not easy to calculate. Ecological disruptions (e.g., pest resistance, pest resurgence, pest replacement) are the unintended consequences of over-reliance on pesticides for pest control, and there are always costs associated with unintended consequences. Ecological backlash in agriculture, which has been thoroughly documented in the scientific literature and experienced repeatedly in the real world, ultimately diminishes the effectiveness of management tactics (Pedigo and Rice 2006b).

For decades, the soybean ecosystem was not challenged annually with widespread use of insecticides and fungicides. As pesticide use in soybeans intensifies, it is important to realize that ecological balance will be tested. The opportunities implied by marketing claims for pest control inputs all have potential challenges:

- Control of insect pests with a neonicotinoid seed treatment represents a convenient and relatively cheap opportunity; dealing with insect populations that develop resistance to neonicotinoids is a potential challenge (Nauen and Denholm 2005).
- Control of weeds with glyphosate is a convenient and cost-effective opportunity; dealing with the fungicidal effects of some formulations of Roundup and their impact on arthropod communities is a potential challenge (Morjan et al. 2002).
- Control of insects with insecticides applied to soybean foliage is an opportunity in response to a real insect threat; dealing with arthropod populations that develop resistance to repeated use of these insecticides is a potential challenge (Yang et al. 2002).
- Control of fungal organisms with a fungicide is an opportunity in response to a real soybean disease threat; dealing with the ecological disruption caused by killing insect-pathogenic fungi with fungicides is a potential challenge (Ragsdale and Koch 2008, in these proceedings).

The potential challenges enumerated in the preceding list have not occurred in soybean fields in Illinois yet, at least as far as we know. However, a quotation from Todd et al. (1994) bears repeating: "... because of the use of IPM tactics, insecticide use on soybean has remained low relative to other row crops, thus reducing the potential for resistance development." In striving toward maximum soybean yield, we need to reflect on this remark made several years ago when insecticide use in soybeans was limited.

In addition to having expectations for higher soybean yields, soybean producers also have greater expectations for insect management guidelines. During the past couple of years, members of the Illinois Soybean Association have asked whether the percentage defoliation thresholds are still reliable for modern soybean varieties grown for high yields with modern production practices.

I conveyed this question to a group of field crop Extension entomologists in the north-central states at a meeting in St. Louis in November 2007. Planting dates have changed, row spacing has changed, plant populations have fluctuated, and the timing of soybean canopy closure has changed since the percentage defoliation thresholds were widely recommended in the 1970s and early 1980s (e.g., Kogan and Kuhlman 1982). Most of us agreed that the percentage defoliation thresholds are not very practical any more. Rather, experts have indicated that treatment decisions should be based on leaf area indices or light interception (Hammond et al. 2000). Unfortunately, there currently are no practical guidelines that support this preferred method of decision making for defoliators of soybeans. So, we continue to use the percentage defoliation thresholds as a contingency.

Producers also wonder why we continue to recommend regular scouting in drilled soybeans or soybeans planted in 15-inch rows after mid-July. And what are the effects of multiple insect species feeding on soybeans, even though the density of each species is below the economic threshold? This question has been asked scientifically (e.g., Hutchins et al. 1988), although not resolved for insect pests causing dissimilar types of injury. These questions and concerns present opportunities for research associated with modern soybean production and insect management strategies, but they are challenges for soybean producers.

Additional glimpses into the future of soybean insect management suggest that host plant resistance will play a significant role. Soybean varieties with putative resistance to soybean aphids are already in development in soybean breeding programs at several land-grant universities, and resistant varieties will be commercialized relatively soon. Assuming that soybean resistance to soybean aphids holds up under field conditions, "conventional" host plant resistance holds real promise for managing soybean aphids. It is also pos-

sible that Bt soybean varieties will be commercialized in the not-too-distant future. However, the Bt soybean lines that have been tested in the United States (MacRae et al. 2005) are resistant to Lepidoptera, a group of insects that, for the most part, has not threatened soybean production in the Midwest for many years.

The previous sentence raises the final point I will make in this paper. Although our primary insect and mite pests of soybeans in the Midwest have been bean leaf beetles, Japanese beetles, soybean aphids, and twospotted spider mites over the past 7 years, a shift in pest species can be induced by significant use of pesticides. Many soybean producers observed large numbers of whiteflies in soybean fields in the Midwest in 2007. More often than not, large whitefly populations in the Midwest have not been identified to species, so their threat to soybeans is difficult to assess (Johnson and Nuessly 1994). The species of whiteflies sampled from a couple of locations in Illinois were identified as greenhouse whiteflies, *Trialeurodes vaporariorum* (Steffey 2007), a species that does not seem to cause economic damage to soybeans. However, some entomologists suspected another species, the more dreaded sweetpotato (or silverleaf) whitefly, *Bemisia tabaci*, which is resistant to many insecticides and has caused economic losses to soybeans in the southeastern United States (Johnson and Nuessly 1994). An experienced entomologist also believed he observed bandedwinged whiteflies, *Trialeurodes abutiloneus* (Kevin Black, personal communication).

Observations of whiteflies in soybean fields in 2007 may have been circumstantial and not related to any of our pest management practices—but we do not know this for certain. The possibility for the occurrence of new pests or the resurgence of old pests in soybeans is just over the horizon if we disregard ecological principles.

## References


Hammond, R.B., L.G. Higley, L.P. Pedigo, L. Bledsoe, S.M. Spomer, and T.A. DeGooyer. 2000. Simulated insect defoliation on soybean: Influence of row width. *Journal of Economic Entomology* 93:1429–1436.

Hutchins, S.H., L.G. Higley, and L.P. Pedigo. 1988. Injury equivalency as a basis for developing multiple-species economic injury levels. *Journal of Economic Entomology* 81:1–8.

Johnson, F.A., and G.S. Nuessly. 1994. Whiteflies, pp. 97–99. In L. G. Higley and D.J. Boethel (eds.). *Handbook of Soybean Insect Pests.* Entomological Society of America, Lanham, MD.

Kogan, M., and D.E. Kuhlman. 1982. *Soybean Insects: Identification and Management in Illinois.* Bulletin 773, Agricultural Experiment Station, College of Agriculture, University of Illinois at Urbana-Champaign.

MacRae, T.C., M.E. Baur, D.J. Boethel, B.J. Fitzpatrick, A.-G. Gao, J.C. Gamundi, L.A. Harrison, V.T. Kabuye, R M. McPherson, J.A. Miklos, M.S. Paradise, A.S. Toedebusch, and A. Viegas. 2005. Laboratory and field evaluations of transgenic soybean exhibiting high-dose expression of a synthetic *Bacillus thuringiensis cry1A* gene for control of Lepidoptera. *Journal of Economic Entomology* 98:577–587.

Morjan, W.E., L.P. Pedigo, and L.C. Lewis. 2002. Fungicidal effects of glyphosate and glyphosate formulations on four species of entomopathogenic fungi. *Environmental Entomology* 31:1206–1212.

Nauen, R., and I. Denholm. 2005. Resistance of insect pests to neonicotinoid insecticides: Current status and future prospects. *Archives of Insect Biochemistry and Physiology* 58:200–215.

Pedigo, L.P., and M.E. Rice. 2006a. Economic decision levels for pest populations, pp. 253–284. In *Entomology and Pest Management,* 5th Edition. Pearson Prentice Hall, Upper Saddle River, NJ.

Pedigo, L.P., and M.E. Rice. 2006b. Managing ecological backlash, pp. 557–587. In *Entomology and Pest Management,* 5th Edition. Pearson Prentice Hall, Upper Saddle River, NJ.

Ragsdale, D.W., and K.A. Koch. 2008. Fungicides: Do they adversely affect beneficial insect pathogens in multiple cropping systems? In *Proceedings of the 2008 Illinois Crop Protection Technology Conference.* University of Illinois, Urbana-Champaign.

Schnitkey, G., and D. Lattz. 2007. Non-land costs for corn and soybeans projected to increase in 2008. *Farm Business Management, Farm Economics Facts & Opinions,* November 6, FEFO 07-17. University of Illinois, Urbana-Champaign. www.farmdoc.uiuc.edu/manage/newsletters/fefo07_17/fefo07_17.html.

Steffey, K. 2007. Whiteflies in soybeans in 2007. In *the Bulletin,* No. 23, article 6, October 5. University of Illinois, Urbana-Champaign. http://ipm.uiuc.edu/bulletin/article.php?id=857.

Todd, J.W., R.M. McPherson, and D.J. Boethel. 1994. Management tactics for soybean insects, pp. 115–117. In L.G. Higley and D.J. Boethel (eds.). *Handbook of Soybean Insect Pests.* Entomological Society of America, Lanham, MD.

Yang, X., L.L. Buschman, K.Y. Zhu, and D.C. Margolies. 2002. Susceptibility and detoxifying enzyme activity in two spider mite species (Acari: Tetranychidae) after selection with three insecticides. *Journal of Economic Entomology* 95:399–406.

# Future Soybean Oil and Meal Traits

*Dennis Byron*

The soybean provides one of the best sources of protein and oil for human and animal nutrition. It is an industry standard for protein and oil. However, it is not perfect for all applications.

Input from the food industry indicated a need for soybean oil trait enhancements that lower the saturated fat content in soybean oil and reduce or eliminate the need for hydrogenation, which results in the production of trans fatty acids. Some components of the food industry also requested improvements in flavor stability to provide more consistency and longer shelf life.

Input from the feed industry suggested that, while soybean meal is a superior source of protein for animal feed, reducing indigestible phosphorous, increasing metabolizable energy, and changing the amino acid balance could help improve animal efficiencies and reduce environmental impacts.

## Low-Linolenic Soybeans

Research on altered linolenic acid content of soybean oil began at Iowa State University in 1968. The research team, led by Walt Fehr and Earl Hammond, identified three genes that individually reduce linolenic acid. The genes are designated as *fan1*, *fan2*, and *fan3*. Different combinations of the three individual genes result in linolenic acid contents that range from 3% to 1%. All three genes are required to reach 1%.

To develop commercial varieties, lines with reduced linolenic content are crossed with the best conventional varieties, and high-yielding "Low Lin" commercial varieties are ultimately selected and released after several years of testing.

These soybean oils with reduced linolenic fatty acid have better flavor stability over nonhydrogenated vegetable oils and rival the flavor stability of lightly hydrogenated oil. Shelf life of products with low lin oil exceed that of nonhydrogenated oil. Best of all, the low linolenic trait reduces or eliminates the need for hydrogenation, which creates trans fat, and it is best suited for commercial frying purposes.

In 2007, approximately 1.5 million acres of low linolenic soybeans were grown and will produce more than 700 million pounds of oil. More than 2 million acres are expected in 2008, including significant acres in Illinois.

Numerous low lin varieties are available from multiple companies. Care must be taken in variety selection to make certain the varieties are adapted to local environments and pest pressures. Premiums for growing low linolenic varieties vary but generally are around $.60 per bushel.

## Increased Oleic Soybeans

The next step in enhanced functionality will be soybean oil with improved oxidative stability and superior flavor stability. Several research programs are developing soybeans with increased levels of oleic fatty acid along with reduced linolenic. Soybeans with higher levels of oleic resist oxidative breakdown even under high heat applications. Fried products and other food products that undergo high heat during processing will benefit from this oil. In addition, products made from this oil have even greater shelf life than products with only low linolenic oils.

Iowa State University will be releasing soybean varieties with mid-oleic content in 2009. These varieties are non-GMO and will have oleic acid levels exceeding 50%, compared to that of current varieties, which typically have oleic levels in the mid-20% range. In addition, the varieties will also have linolenic levels at 1%.

Pioneer is using gene transfer technology to increase the oleic content to approximately 80%. Documents for regulatory approval have been submitted to USDA and FDA. Approvals are expected in 2008, with introductory release of high-oleic varieties projected for 2009. Pioneer high-oleic varieties are expected to have linolenic levels near 3%. Monsanto is also developing soybeans with increased oleic levels. Premiums for increased oleic varieties have not yet been set.

## Low Saturated–Fat Soybeans

In the United States, all food products must be labeled for their total content of saturated fatty acids because of their impact on cardiovascular health. The American Heart Association recommends that the intake of saturated fat be limited to 7% to 10% (or less) of the total calories consumed each day.

Even though soybean oil is not high in saturated fats, it is still significantly higher than canola oil, with about 7% saturates. There is significant research under way to develop varieties with reduced saturates, especially reduced palmitic fatty acid, considered by many scientists to be the fatty acid most detrimental to human health. The saturated fatty acids in conventional soybean oil consist of about 12% palmitate, about 4% stearate, and about 1% of other saturated fatty acids. Low-saturate soybean oil is possible due to two major genes (*fap1* and *fap3*) that have been developed to reduce the palmitate content to about 4%.

The first low-saturate cultivar that was grown commercially in 1996 was developed jointly by Iowa State University and Pioneer Hi-Bred International, Inc. The low-saturate oil from the crop was sold for the first time in fall 1997. It was sold in grocery stores in the midwestern United States and was distributed to schools nationally through the U.S. Department of Agriculture's National School Lunch Program and School Breakfast Program as a means of lowering the saturated fat content of the meals. With only 1 gram of saturated fat per tablespoon (14 grams), the oil matches the saturated fat content of canola oil and reduces by half the saturated fat found in traditional soybeans. Demand for this oil was limited, and the varieties are no longer available.

The goal of most of the research organizations developing modified soybean oil is to achieve perhaps the ultimate soybean oil, which includes a maximum of 3% linolenic fatty acid, oleic acid above 60%, and total saturates less than 7%. This might be the almost perfect "commodity" vegetable oil for optimizing human health while producing food products with exceptional flavor characteristics and superior shelf life. Soybean varieties with the fatty acid combination are expected to be available near 2010.

## Omega-3 Soybeans

Another issue concerning cardiovascular health is increasing the omega-3 fatty acids in soybeans. People must get two types of polyunsaturated fats, known as alpha-linolenic acid (an omega-3 fatty acid) and linolenic acid (an omega-6 fatty acid), from the foods they consume because neither is synthesized in the body. Studies suggest that omega-3 fatty acids have anti-inflammatory properties and cardioprotective benefits.

Soybean oil is one of the few nonfish sources of omega-3s, and it's also rich in omega-6 fatty acids. Health professionals and nutrition experts emphasize the importance of looking at the omega-6 to omega-3 ratio, because Americans tend to overconsume omega-6 fatty acids. Soybean oil features an omega-6 to omega-3 ratio of 1 to 7.5, which is well below the suggested ratio of 1 to 10 that's cited in the new Dietary Reference Intakes.

Monsanto is developing soybean varieties with increased omega-3 fatty acid. The goal of this project is to create an affordable, land-based, renewable source of omega-3s that makes it easier than current alternatives to create great-tasting food products rich in this nutrient. Monsanto expects to have varieties available around 2012.

## Soybean Meal Traits

While the soybean is valued for its high-quality protein, about 25% is composed of various carbohydrates. Most of these are not nutritionally available to poultry and livestock as sources of calories, and some even exhibit negative nutritional qualities in nonruminants. Research on soybean varieties with reduced "negative" oligosaccharides and increased metabolizable energy is under way. These soybeans are lower in indigestible carbohydrates and higher in digestible sucrose, resulting in higher usable energy and more efficient livestock production.

Other meal traits that are under development include a soybean variety with reduced phytate-phosphorus. Much of the phosphorous found in grain and protein meals is bound in phytate compounds. This phosphorus is not nutritionally available for livestock and poultry to digest and thus contributes to the phosphorus of animal waste, an especially serious problem in concentrated livestock feeding operations. To overcome this problem, feed providers add inorganic phosphorus to rations, and excessive phosphorus is excreted in the manure. Experimental reduced phytate soybeans have resulted in improved phosphorus uptake by animals and reduced phosphorus in waste. Additional livestock feeding

trials are under way. Low phytate and low oligosaccharide soybeans may be available around 2010.

Additionally, scientists are working on improving the amino acid composition of soybean protein. Soybeans are inherently low in sulfur-containing amino acids, so research is under way to increase methionine and cysteine to make soybean meal more effective for livestock and poultry. This research uses gene transfer technology and is in the early stages of development. Consequently ,soybeans with improved amino acid profiles will not be available until after 2012.

Many improved soybean oil and meal traits are under development. Demand for enhanced traits will be determined by the value they provide to end users and the ability of all components of the value chain to share in this value. It is likely that multiple oil and meal traits will be required to provide enough value for sustainable utilization of these traits.

# Developing Nutrient Standards for Illinois: Connecting Regulators with Researchers

*George F. Czapar*

In 2000, the United States Environmental Protection Agency (USEPA) published ambient water-quality criteria recommendations for rivers and streams and directed states to set water-quality standards "to protect the physical, biological, and chemical integrity of their waters." The recommended criteria were developed for 14 different ecoregions in the United States, and reference conditions were proposed for total phosphorus, total nitrogen, chlorophyll a, and turbidity. The USEPA reference conditions for Ecoregion 6, which includes approximately the northern two-thirds of Illinois, and Ecoregion 9, which includes the southern one-third of Illinois, are shown in Table 1.

**TABLE 1 • Ambient water quality criteria recommendations (US EPA 2000).**

| Nutrient parameters | Reference conditions, Ecoregion 6 | Reference conditions, Ecoregion 9 |
|---|---|---|
| Total phosphorus (µg/L) | 76.25 | 36.56 |
| Total nitrogen (mg/L) | 2.18 | 0.69 |
| Chlorophyll a (µg/L) | 2.7 | 0.93 |
| Turbidity (FTU) | 6.36 | 5.7 |

Because the reference conditions were based on the 25th percentile for all nutrient data, they did not account for local site conditions that may have significant impacts on water quality. Most waters in Illinois would exceed the proposed nutrient criteria, including some high-quality streams that support a rich diversity of aquatic species but may have elevated nutrient concentrations during high-flow events in the spring.

As a result, developing water-quality standards for nutrients is a challenge facing Illinois and many other states. The USEPA did allow for individual states to adopt other scientifically defensible criteria or adjust them to better reflect state-specific conditions. In Illinois, a collaborative research program was organized to help provide the basis for standard development. This research is funded by the State of Illinois through the Illinois Council on Food and Agricultural Research (C-FAR).

As part of its research focus, C-FAR established the Strategic Research Initiative (SRI) in water quality. This program encourages collaboration among the state universities and other research entities throughout Illinois and brings together scientists to work together for a common purpose. The goals of the Water Quality SRI are (1) to help develop the scientific basis for nutrient standards in the surface waters of Illinois, and (2) to assist in the appropriate development and implementation of Total Maximum Daily Loads (TMDLs).

This initiative required close collaboration with regulatory agencies in Illinois. As part of the SRI, an advisory team from the Illinois Environmental Protection Agency (IEPA) and the Illinois Department of Agriculture identified information gaps and prioritized the most important research needs. A request for proposals was developed from this priority list. The projects that were funded included those from the University of Illinois, Illinois State University, Southern Illinois University, the Illinois State Water Survey, and the Illinois Natural History Survey.

The SRI is organized into four research teams, each with a slightly different focus. Project components include a detailed

analysis of existing IEPA data, intensive sampling at fixed locations, statewide temporal sampling at 140 sites, investigating the effects of sediment on phosphorus dynamics in streams, and improving the methodology for collecting and analyzing algal samples. Laboratory experiments to isolate the effects of phosphorus on algal growth were also conducted.

Because standards need to consider all sources of nutrients, they directly affect both rural and urban residents. The SRI collaborated with two water reclamation districts to collect information on effects of sewage treatment plants on water quality. The shared goal of the Illinois plan is the development of practical and effective nutrient standards based on identified causes and thresholds of water-body use impairment due to nutrient enrichment.

On October 23, 2007, Water Quality SRI researchers participated in a Nutrient Standards Forum that was held at the University of Illinois at Springfield. Each research team presented key findings and summarized their work. Information about the meeting and copies of all presentations are available on the C-FAR Web site at www.ilcfar.org/research/waterqualityforum.html.

The C-FAR strategic research initiative has provided valuable insight in the development of nutrient standards. It has also raised additional questions and identified other factors that may have greater impacts on biotic integrity than nutrient concentration alone. Factors such as physical habitat, sediment, light availability, temperature, and hydrology are part of a complex relationship affecting biotic responses in rivers and streams.

Cause and effect relationships can be difficult to establish because Illinois lacks a wide range of nutrient conditions, and nutrients are almost never the primary limiting factor to algal production. The challenge remains for regulators to adopt practical and effective nutrient standards, but developing partnerships with the research community is an important first step.

Primary funding for this research was provided by the State of Illinois through the Illinois Council on Food and Agricultural Research. Additional funding was provided by the governor of Illinois and the Illinois Environmental Protection Agency through Section 319 of the Clean Water Act. Collaborators include the Illinois Environmental Protection Agency, Illinois Department of Agriculture, Metropolitan Water Reclamation District of Greater Chicago, Bloomington-Normal Water Reclamation District, Oak Ridge National Laboratory, and The Nature Conservancy.

## References

U.S. Environmental Protection Agency. 2000. *Ambient Water Quality Criteria Recommendations: Information Supporting the Development of State and Tribal Nutrient Criteria. Lakes and Reservoirs in Nutrient Ecoregion IX.* U.S. Environmental Protection Agency, Washington, DC. www.epa.gov/waterscience/criteria/nutrient/ecoregions/lakes/lakes_9.pdf

# Gulf Hypoxia: The Saga Continues

*Dennis McKenna*

The hypoxic zone is an area in the northern Gulf of Mexico where dissolved oxygen concentrations in the shallow ocean are less than 2 mg/L, the level necessary to sustain most aquatic life. In response to the low oxygen levels, mobile organisms, such as fish and shrimp, leave the hypoxic zone; the others die at varying rates. Although these responses have been observed in the Gulf, an economic analysis based on past data did not detect a direct relationship between hypoxia and Gulf fisheries (CENR 2000).

The occurrence of hypoxic conditions depends on stratification of the water column—warm, less-dense freshwater above cold, denser saltwater—and consumption of oxygen during the decomposition of organic materials. The organic matter in the lower part of the water column is a result of algal growth and death in the surface waters. The growth of the algae is controlled by the presence of nutrients. In most saltwater systems, nitrogen is commonly the nutrient that limits algal growth. However, in the northern Gulf of Mexico, phosphorus is an important limiting nutrient during the spring and summer of the year in the lower salinity, near-shore regions. In freshwater systems, phosphorus is the nutrient that most often controls algal growth.

The size of the hypoxic zone varies considerably from year to year, depending on the timing and extent of water-column stratification during the spring and summer, weather conditions, temperature, and amount of precipitation in the Mississippi River drainage basin. In 1999, the hypoxic zone was almost 20,000 km$^2$, the greatest extent since measurements began in 1985. In the summer of 2000, it was about 4,400 km$^2$, the smallest area since the drought year of 1988. Hypoxia in bottom waters covered an average of 8,000 to 9,000 km$^2$ in 1985–1992 but increased to 16,000 to 20,000 km$^2$ in 1993–1999. The 5-year running average of the hypoxic zone for 2003–2007 was about 15,000 km$^2$ (Figure 1).

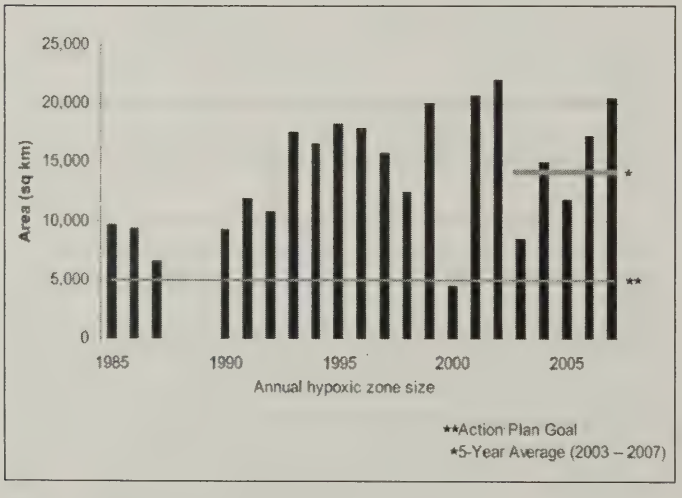


**FIGURE 1 • Size of hypoxic zone in northern Gulf of Mexico, 1985–2007.**

## 2001 Action Plan

The Harmful Algal Bloom and Hypoxia Research and Control Act of 1998 (P.L. 105-383) required that the president, in conjunction with the chief executive officers of the states, submit a plan to reduce, mitigate, and control hypoxia in the northern Gulf of Mexico. The law also required that the plan include the social and economic costs and benefits of the measures for reducing hypoxia.

In 2001, the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force submitted to Congress the Action Plan for Reducing, Controlling, and Mitigating Hypoxia in the Northern Gulf of Mexico (Task Force 2001). The task force is composed of federal agencies and ten state agencies, including the Illinois Department of Agriculture. The task

force has met seven times since 1997 to develop the action plan, which proposed ten short-term actions to achieve long-term coastal, basin, and quality of life goals, as follows: "States, Tribes, and Federal agencies within the Mississippi and Atchafalaya River Basin will

- expand the existing monitoring efforts within the Basin,
- develop strategies for nutrient reduction,
- identify point source dischargers with significant discharges of nutrients and undertake steps to reduce those loadings,
- increase assistance to landowners for voluntary actions to restore, enhance, or create wetlands and vegetative or forested buffers along rivers and streams within priority watersheds, and
- increase assistance to agricultural producers, other landowners, and businesses for the voluntary implementation of best management practices (BMPs), which are effective in addressing loss of nitrogen to waterbodies."

Although it was recognized that implementation of the action plan would require a significant level of commitment from the federal agencies and state governments, the first and most important action item to develop an integrated federal budget proposal was never completed. Consequently, there has been limited progress in achieving the other actions.

## Reassessment of the Hypoxia Action Plan

The 2001 action plan also included an action item to assess the nutrient reductions achieved and the response of the hypoxic zone, water quality throughout the Basin, and economic and social effects. The reassessment (www.epa.gov/msbasin/taskforce/reassess2005.htm) included a series of actions to develop the information necessary for the task force to review the 2001 action plan and make revisions as necessary. These actions included reassessment of the primary causes of Gulf hypoxia and management approaches to address these causes. To capture recent advances in scientific understanding of hypoxia, the causes, and potential solutions, the task force sponsored four scientific symposia, including

- Upper Basin Science Symposium, September 26–28, 2005, Ames, Iowa, which evaluated the effectiveness and cost effectiveness of the various management practices currently available to agriculture to reduce nutrient losses (proceedings available at www.umrshnc.org)
- Gulf Hypoxia Science Symposium, April 25–27, 2006, New Orleans, Louisiana
- Lower Basin Science Symposium, June 1–2, 2006, New Orleans, Louisiana
- Sources, Fate and Transport Symposium, November 7–9, 2006, Minneapolis, Minnesota

The task force recognized the need to have an updated, independent assessment of the causes of Gulf hypoxia and recommendations as to whether the most recent body of scientific evidence supported revisions to the assessment that formed the basis of the 2001 action plan. After review of several options, the task force agreed that an expert panel be chartered through EPA's Science Advisory Board (SAB) to review available scientific information and provide a report that synthesizes the current state of knowledge of the causes of Gulf hypoxia.

The task force selected the SAB because of the opportunities for public access, timeliness, and cost. All SAB panel meetings and deliberations are open to the public in accordance with the Federal Advisory Committee Act and EPA administrative policies for advisory committee management. The EPA Science Advisory Board Hypoxia Advisory Panel (www.epa.gov/sab/panels/hypoxia_adv_panel.html) was charged with evaluating the scientific basis for, and recommending revisions to, the goals proposed in the action plan, and the scientific basis for the efficacy of recommended management.

The specific charges to the panel included the following:

***1. Characterization of Hypoxia***—The development, persistence and areal extent of hypoxia is thought to result from interactions in physical, chemical, and biological oceanographic processes along the northern Gulf continental shelf; and changes in the Mississippi River Basin that affect nutrient loads and freshwater flow.

A. Address the state-of-the-science and the importance of various processes in the formation of hypoxia in the Gulf of Mexico. These issues include

   i. increased volume or funneling of freshwater discharges from the Mississippi River;

   ii. changes in hydrologic or geomorphic processes in the Gulf of Mexico and the Mississippi River Basin;

   iii. increased nutrient loads due to coastal wetlands losses, upwelling, or increased loadings from the Mississippi River Basin;

   iv. increased stratification, and seasonal changes in magnitude and spatial distribution of stratification and nutrient concentrations in the Gulf;

   v. temporal and spatial changes in nutrient limitation or co-limitation, for nitrogen or phosphorus, as significant factors in the development of the hypoxic zone; and

vi. the implications of reduction of phosphorus or nitrogen without concomitant reduction of the other.

B. Comment on the state of the science for characterizing the onset, volume extent, and duration of the hypoxic zone.

***2. Characterization of Nutrient Fate, Transport, and Sources***—Nutrient loads, concentrations, speciation, seasonality, and biogeochemical recycling processes have been suggested as important causal factors in the development and persistence of hypoxia in the Gulf. The Integrated Assessment (CENR 2000) presented information on the geographic locations of nutrient loads to the Gulf and the human and natural activities that contribute nutrient loadings.

A. Given the available literature and information (especially since 2000), data and models on the loads, fate and transport, and effects of nutrients, evaluate the importance of various processes in nutrient delivery and effects. These may include

i. the pertinent temporal (annual and seasonal) characteristics of nutrient loads/fluxes throughout the Mississippi River Basin and, ultimately, to the Gulf of Mexico;

ii. the ability to determine an accurate mass balance of the nutrient loads throughout the basin; and

iii. nutrient transport processes (fate/transport, sources/sinks, transformations, etc.) through the basin, the deltaic zone, and into the Gulf.

B. Given the available literature and information (especially since 2000) on nutrient sources and delivery within and from the basin, evaluate capabilities to

i. predict nutrient delivery to the Gulf, using currently available scientific tools and models; and

ii. route nutrients from their various sources and account for the transport processes throughout the basin and deltaic zone, using currently available scientific tools and models.

***3. Scientific Basis for Goals and Management Options***—The task force has stated goals of reducing the 5-year running average areal extent of the Gulf of Mexico hypoxic zone to less than 5,000 km$^2$ by the year 2015, improving water quality within the basin and protecting the communities and economic conditions within the basin. Additionally, nutrient loads from various sources in the Mississippi River Basin have been suggested as the major driver for the formation, extent, and duration of the Gulf hypoxic zone.

A. Are these goals supported by present scientific knowledge and understanding of the hypoxic zone, nutrient loads, fate and transport, sources, and control options?

i. Based on the current state-of- the-science, should the reduction goal for the size of the hypoxia zone be revised?

ii. Based on the current state-of-the-science, can the areal extent of Gulf hypoxia be reduced while also protecting water quality and social welfare in the basin?

B. Based on the current state-of-the-science, what level of reduction in causal agents (nutrients/discharge) will be needed to achieve the current reduction goal for the size of the hypoxic zone?

C. Given the available literature and information (especially since 2000) on technologies and practices to reduce nutrient loss from agriculture, runoff from other nonpoint sources, and point source discharges, discuss options (and combinations of options) for reducing nutrient flux in terms of cost, feasibility, and any other social welfare considerations. These options may include

i. the most effective agricultural practices, considering maintenance of soil sustainability and avoiding unintended negative environmental consequences;

ii. the most effective actions for other nonpoint sources; and

iii. the most effective technologies for industrial and municipal point sources.

## Findings of the Hypoxia Advisory Panel

The following is excerpted from the Science Advisory Board Hypoxia Panel Advisory Draft Report (www.epa.gov/sab/panels/hypoxia_adv_panel.htm):

- Recent science has affirmed that contemporary changes in the hypoxic area in the northern Gulf of Mexico are primarily related to nutrient loads from the basin.
- The 5,000 km$^2$ target remains a reasonable endpoint for continued use in an adaptive management context; however, it may no longer be possible to achieve this goal by 2015.
- To reduce the size of the hypoxic zone and improve water quality in the basin, the SAB panel recommends a strategy targeting at least a 45% reduction in total nitrogen flux and at least a 45% reduction in total phosphorus flux.

- Phosphorus limitation is now occurring because of excessive N loadings over the past 50 years, which have dramatically altered nitrogen to phosphorus ratios.
- One physical factor that has changed substantially over the past century is river hydrology due to the diversion of a large amount of freshwater from the Mississippi River through the Atchafalaya River to the Atchafalaya Bay and maintenance of this diversion by the U.S. Army Corps of Engineers. The major injection of freshwater into Atchafalaya Bay, some 200 kilometers to the west of the Mississippi River delta, has profoundly modified the spatial distribution of freshwater inputs, nutrient loadings, and stratification on the Louisiana–Texas continental shelf.
- The latest USGS estimates show that total N flux averaged 1.24 million metric tons/yr from 2001–2005 (65% of the flux is nitrate), and the total P flux averaged 154,000 metric tons/yr. This change represents a 21% decline in total N flux and a 12% increase in total P flux when compared with the averages from the 1980–1996 time period.
- The spring (April–June) flux of nutrients appears to be an important determinant of hypoxia, for that is when the river is disproportionately enriched with both N (especially nitrate) and P. Spring total N flux has declined since the 1980s; whereas total P flux shows a 9.5% increase (when average total P flux for 2001–2005 is compared with the 1980–1996 average).
- USGS data also show that during the past 5 years, the Upper Mississippi and Ohio–Tennessee sub-basins contributed 80% of total N flux and 64% of total P flux, although these sub-basins represent only 32% of the entire Mississippi/Atchafalaya River Basin (MARB) area.
- Ballpark estimates of point source discharge show that point sources represented 22% of total N flux and 34% of total P flux during the past five years.
- Net anthropogenic N inputs (NANI) for the MARB have declined in the past decade because of increased crop yields, reduced livestock populations, and little change in N fertilizer inputs.
- From 1999–2005, NANI calculations show 54% of non-point N inputs in the MARB were from fertilizer, 37% from fixation, and 9% from atmospheric deposition.
- Changes in benthic and fish communities in the Gulf of Mexico with the change in frequency of hypoxia are cause for concern and suggest that the Gulf has undergone a regime shift.
- The Gulf of Mexico ecosystem is more sensitive to inputs of nutrients than in the past, with nutrient inputs inducing a larger response in hypoxia.
- Certain aspects of the nation's current agricultural and energy policies are at odds with the goals of hypoxia reduction and improving water quality.
- The SAB panel's calculations suggest that tighter limits on N and P in effluent (3 mg N/L and 0.3 mg P/L) from sewage treatment plants could realize an estimated 11% reduction in annual average total N flux and a 21% reduction in total annual average P flux to the Gulf.
- Restructuring subsidies and conservation programs represents an important tool for reducing nutrient runoff from agricultural production.

## The 2008 Action Plan

In November 2007, the task force released a draft of the 2008 action plan for public comment. One significant change from the 2001 plan was to propose that nutrient reduction strategies to meet the goals of the action plan be developed at a state level rather than for the large sub-basin or national scale. The Task Force recognized that no single approach to nutrient reduction would be effective in every state within the Mississippi River Basin because the soils, hydrology, land use, and cropping practices as well as the legal, legislative, and administrative framework vary considerably across the 31 states in the basin. These strategies will provide a road map for each state, a more detailed basis for budget development, and a vehicle for coordination with other states in the basin. Once the strategies have been adopted and new funding is provided, federal and state agencies can accelerate efforts to reduce nutrient impacts on local waters and the Gulf.

The task force (www.epa.gov/msbasin/taskforce/pdf/2008draft_actionplan.pdf) also proposed amending the coastal goal to read as follows: "Subject to the availability of additional resources, we strive to reduce or make significant progress towards reducing the 5-year running average [areal] extent of the Gulf of Mexico hypoxic zone to less than 5,000 square kilometers by the year 2015 through implementation of specific, practical, and cost effective voluntary actions by all States, Tribes, and address all categories of sources and removals within the Mississippi/Atchafalaya River Basin to reduce the annual discharge of nitrogen and phosphorus into the Gulf."

The modification of the goal was prompted by the difficulty of meeting the 2015 goal. As the Science Advisory Board concluded, "The 5,000 km$^2$ target remains a reasonable end-

point for continued use in an adaptive management context; however, it may no longer be possible to achieve this goal by 2015 ... It is even more important to proceed in a directionally correct fashion to manage factors affecting hypoxia than to wait for greater precision in setting the goal for the size of the zone. Much can be learned by implementing management plans, documenting practices, and measuring their effects with appropriate monitoring programs" (SAB 2007).

## References


Mississippi River/Gulf of Mexico Watershed Nutrient Task Force. 2001. *Action Plan for Reducing, Mitigating, and Controlling Hypoxia in the Northern Gulf of Mexico*. Washington, DC. www.epa.gov/msbasin/taskforce/actionplan.htm

Natural Science and Technology Council Committee on Environment and Natural Resources (CENR). 2000. *Integrated Assessment of Hypoxia in the Northern Gulf of Mexico*. Natural Science and Technology Council Committee on Environment and Natural Resources, Washington, DC. 58 pp. www.nos.noaa.gov/products/pubs_hypox.html.

Science Advisory Board (SAB). 2007. *Science Advisory Board (SAB) Hypoxia Panel Draft Advisory Report* (Working Draft). U.S. Environmental Protection Agency, Washington, DC. www.epa.gov/sab/pdf/11-5-07_hap_draft.pdf.

# Considerations for Managing Nitrogen When Switching from Corn–Soybean to Corn–Corn Rotations

*T.S. Murrell*

There are many questions producers and their advisers are asking as more corn is being incorporated into crop rotations. In this article, we focus on a few key questions related to switching from corn–soybean (CS) to corn–corn (CC) rotations.

## How Much Do I Need to Change My Nitrogen (N) Rate?

The following factors will need to be considered when deciding how much N to apply to corn in CC versus CS systems:

**Soybean N credit.** Many recommendation algorithms have a soybean N credit that reduces the N rate. Most states use a constant, which ranges across states from 30 to 45 lb N/A (Figure 1). Other states use a credit of 0.5 to 1 lb N/bu of soybean yield, with some caveats for yield level. When soybean is omitted from the rotation, this credit is sacrificed.

**Soil nitrate level.** Soybeans are good scavengers of soil nitrate. When soybeans are omitted and the switch is made to CC, residual soil nitrate levels may increase, although levels are very dependent on the weather. Drier years typically produce higher levels of residual nitrate. Given such variability, it is usually a good practice to test for residual soil nitrate before deciding how much N to apply.

**Attainable yield.** University research has shown that there is a potential for CC systems to yield, on average, less than CS systems when managed in the same way. This possibility reinforces the need to keep accurate yield records on fields. If, over time, yields have in fact decreased, N rates will need to be adjusted downward in recommendation systems using yield goal as a factor.

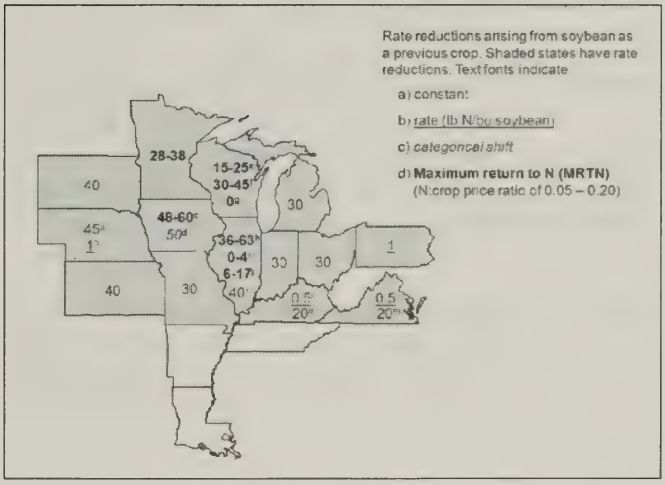


**FIGURE 1 • Data taken from state Extension publications and the online regional MRTN database.**

State specific notes:

**Nebraska**

[a] Constant used when soybean yield is equal to or greater than 30 bu/A.

[b] Rate used when soybean yield is less than 30 bu/A.

**Iowa**

[c] Range in MRTN from online database.

[d] Categorical shift in ranges given in pub. PM1714 (Blackmer et al. 1997).

**Wisconsin**

[e] High/very high yield potential soils.

[f] Medium/low yield potential soils.

[g] Sands/loamy sands.

**Illinois**

[h] Northern Illinois

[i] Central Illinois

[j] Southern Illinois

[k] Constant given in *Illinois Agronomy Handbook* (Hoeft and Nafziger 2002).

**Kentucky and Virginia**

[l] Rate when previous soybean crop yield is known.

[m] Constant used when previous soybean crop yield is unknown.

Tools are available to assess how well corn is being fed with N. Of course, visual inspections can identify more severe cases where deficiency symptoms are apparent. Many states provide guidance for using a chlorophyll meter to identify more obscure, in-season N nutrition problems. Finally, the stalk nitrate test can be used at the end of the season to assess the appropriateness of the N rates used. Incorporating some or all of these monitoring tools can be very helpful when the switch is first made from CS to CC.

## What Happens to Soil pH When I Apply N More Often?

Switching from CC to CS means applying N every year, rather than biennially. Most N fertilizers have an acidifying effect on soils. In some cases, the initial reaction may be alkaline, but, over the long run, the ultimate reaction is acid. There are a few reasons for this:

**Nitrification.** This natural process in soils is the conversion of ammonium-N ($NH_4^+$) to nitrate-N ($NO_3^-$). The conversion of one mole of $NH_4^+$ produces two moles of acidity ($H^+$). Common commercial N fertilizer sources either directly contain or produce $NH_4^+$ and are therefore ultimately acid in reaction.

**Nitrate leaching.** The downward movement of $NO_3^-$ is accompanied by positively charged ions (cations), most commonly basic cations, such as calcium and magnesium. This process ultimately leaves a greater proportion of acidic cations in the surface soil.

**Volatilization.** Under some conditions, such as basic pH, $NH_4^+$ converts to ammonia ($NH_3$). One mole of $NH_4^+$ produces one mole of $H^+$.

**Increased uptake of basic cations.** Where N is needed, fertilization increases plant biomass and uptake of basic cations from the soil.

Whether soil acidification rates will increase with CC compared to CS depends a lot on the soil. A study in Iowa showed no differences in acidification between rotations after 23 or 48 years (Russell et al. 2006). Conversely, a Nebraska study (Table 1) showed that CC rotations decreased soil pH more than CS systems when measured after 14 years (Liebig et al. 2002). Both studies demonstrated that N fertilization increased acidification. The possible influence of rotation and the known impact of N fertilization on soil acidification reinforce the need to regularly monitor soil pH, especially in the first few years, when switching from one rotation to the other.

**TABLE 1 • Changes in soil pH after 16 years of cropping on a Sharpsburg silty clay loam** (Liebig et al. 2002; Liebig, personal communication).

| | N rate[1] | | |
|---|---|---|---|
| Rotation[2] | Zero | Low | High |
| *0- to 3-in. depth* | | | |
| CC | 6.45 | 6.19 | 5.51 |
| CS | 6.65 | 6.43 | 6.32 |
| *0- to 12-in. depth* | | | |
| CC | 6.89 | 6.65 | 6.05 |
| CS | 6.86 | 6.59 | 6.71 |

[1] Annual N rates for corn were 0, 80, and 160 lb N/A; annual rates for soybean were 0, 30, and 60 lb N/A. Ammonium nitrate was the N source, applied in the spring of each year.

[2] CC = corn–corn; CS = corn–soybean; corn stalks were shredded, soil disked once or twice (4 to 6 in. deep), then harrowed just prior to planting.

## How Does Nutrient Removal Change?

To answer this question, let's examine the quantity of nutrients removed in CC and CS. Table 2 shows, at the yields assumed, that a CC sequence removes more phosphorus (P), magnesium (Mg), and sulfur (S) than a CS sequence but less N and potassium (K). Just how large such differences are depends on the yield levels of each crop. To estimate this for yourself, multiply your corn and soybean yields by the values in Table 3.

## Do I Need to Consider Applying Starter Fertilizer?

The benefits of starter fertilizer have long been recognized. Placement of N, P, K, and other nutrients in a concentrated

**TABLE 2 • A comparison of nutrient removal for 2 years of corn compared to 1 year of corn and 1 year of soybeans, holding corn yield constant at 180 bu/A and soybean yield at 60 bu/A.**

| | 2-year nutrient removal | | | | |
|---|---|---|---|---|---|
| Rotation | N | $P_2O_5$ | $K_2O$ | Mg | S |
| | | | *(lb/A)* | | |
| Corn–corn (CC) | 324 | 137 | 97 | 32 | 29 |
| Corn–soybean (CS) | 390 | 119 | 127 | 29 | 25 |
| Difference (CC) – (CS) | –66 | 18 | –29 | 4 | 4 |

**TABLE 3 • Average nutrient removal rates calculated from published coefficients in the north central United States (Murrell 2005).**

| | Removal coefficients | | | | |
|---|---|---|---|---|---|
| | N | $P_2O_5$ | $K_2O$ | Mg | S |
| | *(lb/bu)* | | | | |
| Corn | 0.90 | 0.38 | 0.27 | 0.09 | 0.08 |
| Soybean | 3.8 | 0.84 | 1.3 | 0.21 | 0.18 |

band near the seed at planting often results in early-season growth responses that can translate to end-of-season yield increases. Several factors affect response to starter fertilizer. Soil conditions that increase the probability of response include

- cool, moist soil conditions at planting
- longer-season hybrids planted later in the spring
- root growth restrictions, such as soil compaction, soil acidity, and soil salinity

In a 4-year Minnesota study, starter fertilizer produced equally beneficial responses (8 bu/A average) for CC and CS under a variety of tillage systems: no-till, zone till, strip till, and conventional tillage (Vetch and Randall 2002). The need for starter fertilizer for corn, regardless of rotation, may arise from the rapid influx of nutrients by corn roots early in the season and the positive effect of N and P on root proliferation.

## References


Blackmer, A.M., R.D. Voss, and A.P. Mallarino. 1997. *Nitrogen Fertilizer Recommendations for Corn in Iowa.* PM1714. Iowa State University Extension, Ames.

Hoeft, R.G., and E.D. Nafziger. 2002. Soil testing and fertility, pp. 91–131. In P. Picklesimer (ed.). *Illinois Agronomy Handbook.* Universoty of Illinois, Urbana-Champaign.

Liebig, M.A., G.E. Varvel, J.W. Doran, and B.J. Wienhold. 2002. Crop sequence and nitrogen fertilization effects on soil properties in the western corn belt. *Soil Science Society of America Journal* 66:596–601.

Murrell, T.S. 2005. *Average Nutrient Removal Rates for Crops in the Northcentral Region.* www.ipni.net/northcentral/nutrientremoval.

Russell, A.E., D.A. Laird, and A.P. Mallarino. 2006. Nitrogen fertilization and cropping system impacts on soil quality in Midwestern mollisols. *Soil Science Society of America Journal* 70:249–255.

Vetch, J.A., and G.W. Randall. 2002. Corn production as affected by tillage system and starter fertilizer. *Agronomy Journal* 94:532–540.

# Hypoxia and the Upper Mississippi River Basin: How Can We Reduce Nutrient Losses from Agriculture?

*Mark B. David*

The recent USEPA Science Advisory Board (SAB) Hypoxia Panel report reaffirmed the importance of nitrogen (N) transported down the Mississippi River as a major factor determining the size of the hypoxic zone that forms each summer in the Gulf of Mexico. The SAB report also concluded that phosphorus (P) was an additional important factor that was not previously recognized. Therefore, the SAB panel recommended that the transport of both nutrients would need to be reduced by 45% (from 1980 to 1996 loads) to meet the goal of reducing the hypoxic zone to 5,000 $km^2$ (~2000 $mi^2$). Recently (since 2001) the size of the hypoxic zone has been 16,500 $km^2$ (~6400 $mi^2$). This reduction in nutrients would benefit both the Gulf as well as local water quality conditions in the Mississippi River Basin (MRB). Finally, the panel concluded that the greatest emphasis needed to be placed on the spring (April, May, and June) load of N to the Gulf.

Most of the nitrate load to the Gulf comes from the upper Mississippi and Ohio–Tennessee River sub-basins, as well as more than half of the total P load. A major source area documented by the SAB panel for nitrate was the upper Mississippi River between Clinton, Iowa, and Grafton, Illinois, which includes the Illinois River. The tile-drained, corn and soybean landscape of Iowa, Illinois, Indiana, and Ohio was highlighted as the critical source area of nitrate to the Gulf, as well as nearly all of the spring load. Sewage effluent and other point sources were found to be a relatively small portion (14%) of the spring nitrate load. For P, these same sub-basins were important sources, although other areas of the basin also contributed P, and sewage effluent (and other point sources) was about 34% of the annual P load and 27% of the spring load.

In terms of nutrient balances, the SAB report found that, in the upper Mississippi sub-basin, the N balance had declined quite a bit recently, due to the combination of greater yields, declining manure inputs, and steady fertilizer use. These changes may be leading to a depletion of soil organic matter (and soil organic N) in corn and soybean rotations, because N leaching losses have remained high.

For P, the nutrient balance is now negative, with more P removed in grain in the upper Mississippi sub-basin than applied as fertilizer plus manure. Again, however, P losses to streams and rivers have not declined.

Finally, given current nutrient inputs and outputs in the upper Mississippi River sub-basin, the loss of N and P from fields to streams is not thought to be due to overapplication of fertilizers, but rather leakiness in the corn and soybean production system now in place. This means that even when current best management practices are followed, losses of N and P may be too great—and additional measures will need to be implemented.

Given this background, producers in the tile-drained corn and soybean landscape of the Midwest will likely receive new pressure to reduce losses of both N and P (and non-tiled land for P), as will sewage treatment plants for P. What could we do within corn and soybean agriculture to reduce nutrient losses? Who will pay for these changes? When will they need to be implemented?

I can't really address the latter two questions, which are quite important and certainly influence the first question. I can, however, lay out what the SAB panel concluded were options for reducing N and P losses from agricultural fields, with a focus on the tile-drained landscape.

One conclusion was clear from the SAB report—the idea that there is a "one size fits all" land use or conservation practice that would be cost effective everywhere—was clearly not true or appropriate. An overall conclusion was that there needed

to be site-specific and regional conservation practices with targeting of conservation practices and measures with a broad range of alternative practices and land uses such as crop, animal, fertilizer, and drainage management measures.

Another important conclusion was that practices that might be effective in tile-drained landscapes can be very different from those appropriate for non-tiled lands.

In the following paragraphs, I will highlight what practices might be effective. They might not be desirable from a view of current production methods and income sources, but perhaps they will lead to new production methods that maintain yields *and* reduce nutrient losses. These new production systems will likely increase costs, and who pays those costs will need to be worked out.

The SAB panel concluded that the greatest reduction in both nitrate and P loss from tile-drained fields, and P loss from other fields, would result from alternative and more complex cropping systems that might include perennials. However, it was recognized that current constraints in our agricultural production systems would likely not allow for these changes at this time. If a market for new cellulosic biomass crops such as switchgrass or Miscanthus were to develop, that could change. Biomass crops that need little fertilization and maintain plant cover throughout the year would clearly minimize N and P losses.

Given that there won't be a change to cellulosic biomass energy crops soon, the following recommendations were made for reduced spring nitrate loss in tile-drained regions:

- reduce or discontinue fall N application for corn
- improve N fertilizer management techniques
- use cover crops
- establish wetlands
- implement drainage management techniques

For P loss, recommendations included

- riparian buffer strips
- improved P fertilizer and manure management
- cover crops

Some complications were pointed out, including that controlled drainage could reduce nitrate losses but might increase surface runoff and, therefore, particulate loss of P. It was recognized that cover crops increase costs and risk to the cash crop, and that wetlands and buffer strips can remove land from production and cannot be placed at the edge of every field. However, the recommended practices are what we have available to reduce nutrient loss from fields in our current production systems.

For reducing spring nitrate losses, one of the lowest-cost techniques would be to discontinue fall N application. Most years, this will likely reduce losses and would not include construction or installation costs. However, even if fall N application were completely stopped, it would not lead to a 45% reduction in spring N loads to the Gulf; other practices would have to be implemented with higher costs.

For P, incorporation of P fertilizer into the soil is one lower-cost practice that could reduce losses. Again, however, this one practice will not lead to 45% reductions.

To meet 45% reduction goals for both N and P, many of the recommended practices would need to be incorporated into most fields in areas where losses are highest (targeted implementation). These practices have a range of costs, many of which are substantial, but they would need to be implemented to reduce N and P losses to the level necessary to reduce the hypoxic zone. Unfortunately, there is no simple and inexpensive solution that could be easily applied.

In conclusion, the corn and soybean crop production system now in place in the Midwest leads to losses of N and P that cause hypoxia in the Gulf of Mexico, even if all current recommendations and best management practices are followed. There are cropping systems and on- and off-field practices that could greatly reduce N and P losses, but they have costs and can increase risk. There is no single, overall solution at no or very low cost.

If we want profitable production systems and reduced N and P losses, then new cropping systems combined with a revised conservation and subsidy payment system would be necessary to allow for the full range of practices described in this article to be implemented.

# Mechanisms of Fungicide Resistance and a Case Study of Fungicide Resistance in Potato Production

*Neil C. Gudmestad*

The development of resistance to fungicides in plant pathogenic fungi has become an increasingly more important problem worldwide. There are a number of reasons for this. First, nearly all modern fungicides have a single site mode of action, providing an opportunity for a pathogen to develop resistance with only a single mutation. Second, fungicide use has risen dramatically in the past 10 years, thereby increasing the selection pressure placed on many pathogen populations. This paper will attempt to summarize the mechanisms and factors that lead to the development of fungicide resistance and provide examples on the successful and unsuccessful attempts to prevent fungicide resistance from developing.

## Factors Affecting Fungicide Resistance Development

Numerous factors interact and affect the development of fungicide resistance. These factors include population dynamics of the pathogen involved, mode of action of the fungicide, the level of control provided by the fungicide, frequency of fungicide use, persistence of the fungicide, and the reproduction of the fungus. Each of these factors will be discussed in some detail.

### POPULATION DYNAMICS

Polycyclic pathogens, such as foliar disease–causing fungi, are more likely to develop resistance to fungicides than monocyclic pathogens. The reasons are quite obvious. A fungicide-resistant "mutant" is likely present in any fungal pathogen population at an initial frequency of 1 in 1–10 billion spores of the pathogen in a wild type population. Once this population is exposed to a fungicide with a single site mode of action, the proportion of the individuals that can resist the fungicide survives and will increase in proportion to the sensitive population. It is only when the proportion of the resistant pathogens reaches between 1 in 1,100 and 1 in 10 that the presence of a resistant population is evident or detectable. This is why the development of fungicide resistance often appears to occur abruptly when, in reality, it has been building up over some length of time—albeit at undetectable levels.

### MODE OF ACTION

The mode of action of many fungicides is to bind or inactivate a key enzyme that regulates life-sustaining processes in the fungal pathogen. This would be an example of a single site mode of action, as previously mentioned. All that is required for a fungus to resist the action of a single site fungicide is a change in a single gene or a mutation. In fungicides that have multiple sites of action, more than one life-sustaining process is affected, and the ability to resist the action of more than one of these becomes highly unlikely. This is why fungicides with multiple sites of action, such as mancozeb or chlorothalonil, have never successfully had a resistant pathogen population develop. Simply stated, too many gene changes or mutations would be required before a resistant isolate could withstand the activity of a fungicide with multiple sites of action.

There are exceptions to this general rule. Despite the fact that triazole (DMI) fungicides have a single site mode of action—specifically, they inhibit sterol biosynthesis—the development of resistance to this class of fungicide is a multi-step process involving multiple gene or mutation changes. No single gene in plant pathogenic fungi conveys full resistance to triazole fungicides. Rather, multiple mutations are required, each of which provides small decreases in fungicide sensitivity and loss in efficacy. For this reason, the development of resistance

to triazole fungicides develops slowly over time and can be effectively managed in many instances.

#### LEVEL OF CONTROL

It may seem counter-intuitive, but the selection of fungicide-resistant individuals in a population of a plant pathogen is more likely to build up rapidly when fungicide efficacy is high. Highly efficacious products place a greater degree of selection pressure on the pathogen. In other words, products that provide 95% disease control place more pressure on the pathogen than products that provide only 80% disease control.

#### FREQUENCY OF USE

The selection and buildup of fungicide-resistant individuals is greater the more times a fungicide or fungicide group is used. This is more likely to occur if sequential applications of the same chemistry are made in the absence of alternations with other modes of action. For example, if only two to four applications of a fungicide are made on a crop to control a foliar disease and only QoI (strobilurin) fungicides are used, the target pathogen is more likely to develop resistance to this class of fungicide than if QoI and triazole fungicides were alternated.

#### PERSISTENCE OF THE FUNGICIDE

The longer fungicide residues remain on or in the plant, the more exposures a polycyclic pathogen will have to the same chemistry and the greater the selection pressure.

#### REPRODUCTION OF THE FUNGAL PATHOGEN

Sexual reproduction in a fungus allows for increased variation of genetic material within the fungal population. Fungi that reproduce only asexually do not have as great an opportunity for genetic variability. Fungal plant pathogens that reproduce sexually, in general, have a greater likelihood of developing resistance to fungicides and for this trait to be genetically stable. However, many asexually reproducing plant pathogens produce multiple generations of spores per year and are also capable of becoming resistant to fungicides.

## Case Study of Fungicide Resistance in Potatoes

Potato growers have been plagued by the development of fungicide resistance in a number of important pathogens. The dry rot and silver scurf pathogens, *Fusarium sambucinum* and *Helminthosporium solani*, respectively, developed resistance to benzimidazoles (FRAC group 1) in the early 1990s. Two *Phytophthora*-caused diseases, late blight and pink rot, caused by *P. infestans* and *P. erythroseptica*, respectively, have developed resistance to mefenoxam (FRAC group 4). Among these pathogens, only the late blight pathogen is polycyclic, capable of producing multiple generations of spores during a growing season—hereby increasing exposure to fungicide chemistry. Furthermore, only *P. erythroseptica* has the ability to reproduce sexually. Therefore, it is obvious that, although we can make general statements about factors that affect the development of fungicide resistance, exceptions occur and valuable disease control chemistry can be lost. The development of resistance to fungicides among these disease-causing potato pathogens has been very problematic for the potato industry and has left serious voids in disease management options.

QoI fungicides (strobilurins; FRAC group 11) were introduced in the late-1990s in the United States. Azoxystrobin (Quadris®, Syngenta) was registered for use on potato in 1999. This fungicide provided excellent control of early blight, caused by *Alternaria solani*. Early blight disease pressure in the midwestern United States is usually high due the frequent formation of dew at night. The fungus that causes early blight survives in debris from the previous crop and requires alternating wet and dry periods for infection and subsequent production of secondary cycles of inoculum. Standard protectant fungicides such as mancozeb and chlorothalonil are frequently inadequate alone to provide full-season control of this foliar disease. Azoxystrobin initially provided excellent control of early blight and was so efficacious that many potato growers made four to six applications of the chemical per season, alternated with standard protectants.

A decrease in the level of disease control provided by azoxystrobin was first observed during the summer of 2000 in Nebraska and subsequently in North Dakota in 2001 (Pasche et al. 2004). It was also determined that the mechanism of QoI resistance in *A. solani* was the presence of the F129L mutation (Pasche et al. 2004, 2005). This mutation conveys a 10–15× loss in sensitivity to the QoI fungicides azoxystrobin and pyraclostrobin (Headline®, BASF) and effectively reduces the efficacy of these two fungicides, making them equivalent to mancozeb and chlorothalonil (Pasche and Gudmestad 2007). Because QoI fungicides represent a premium-priced option, we no longer recommend them for the control of early blight in the Midwest.

Interestingly, the effect of the F129L mutation is differential in its impact on other QoI fungicides, such as trifloxystrobin (Gem®, Bayer CropScience), famoxadone (Tanos®, DuPont), and fenamidone (Reason®, Bayer CropScience). The F129L mutation conveys only a 2–3× loss in sensitivity, which does

**TABLE 1 • Number and percentage of F129L mutant isolates of *Alternaria solani* collected from across the United States from 2002 to 2006 (from Pasche and Gudmestad 2007).**

| | 2002[2] | | 2003 | | 2004 | | 2005 | | 2006 | | 2002–2006 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| State[1] | Total[3] | % Mutant[4] | Total | % Mutant | Total | % Mutant | Total | % Mutant | Total | % Mutant | Total | % Mutant |
| Nebraska | 240 | 98.8 | 247 | 100.0 | 758 | 99.0 | 46 | 100.0 | 9 | 88.9 | 1300 | 99.3 |
| Minnesota | — | — | — | — | 767 | 96.7 | 136 | 91.9 | 309 | 92.2 | 1212 | 95.7 |
| North Dakota | 181 | 100.0 | 225 | 91.2 | 230 | 98.7 | 66 | 97.0 | 58 | 62.1 | 760 | 93.8 |
| Wisconsin | — | — | — | — | — | — | 258 | 96.1 | 138 | 89.1 | 396 | 93.7 |
| Michigan | — | — | 11 | 100.0 | 148 | 94.1 | 55 | 98.2 | — | — | 214 | 96.7 |
| Texas | — | — | 1 | 100.0 | 60 | 100.0 | 131 | 98.5 | — | — | 192 | 99.0 |
| Colorado | — | — | 9 | 100.0 | — | — | 20 | 100.0 | 78 | 91.0 | 107 | 93.5 |
| Idaho | — | — | — | — | — | — | 26 | 15.4 | — | — | 26 | 15.4 |
| Wyoming | — | — | — | — | — | — | 13 | 23.1 | — | — | 13 | 23.1 |
| Oregon | — | — | — | — | — | — | — | — | 10 | 60.0 | 10 | 60.0 |
| Washington | — | — | — | — | — | — | 8 | 12.5 | — | — | 8 | 12.5 |
| Total | 421 | 99.3 | 493 | 95.9 | 1963 | 98.4 | 759 | 91.4 | 602 | 87.9 | 4238 | 96.5 |

[1] State from which isolates were originally collected.

[2] Year isolate was collected.

[3] Total number of isolates examined for a given time period.

[4] Percentage of isolates determined to contain the F129L mutation for a given time period.

not appear to affect fungicide efficacy of these chemistries (Pasche et al. 2004, 2005). This is highly unusual because the only other mutation detected in nature that induces resistance to QoI fungicides, the G143A mutation, conveys resistance factors of several hundred or a thousand times lower sensitivity to all QoI fungicides and a complete loss of disease control. Unfortunately, the other QoI fungicides were never as efficacious in the control of early blight as azoxystrobin and pyraclostrobin. For this reason, there remains a need in the potato industry for fungicides that provide enhanced control of early blight in the midwestern United States.

We initially hypothesized that the development of resistance in *A. solani* to QoI fungicides was caused by the repeated exposure of the pathogen to this chemistry. Although we could find no evidence of growers abusing the chemical through sequential applications without alternations with other fungicides, potato producers did apply multiple applications each season, consistent with the label. Our investigations led us to believe that the development of resistance occurred in *A. solani* populations because potato growers used 10 to 12 applications over a 2-year period (Pasche et al. 2004). The frequency of resistance to QoI in the early blight fungus in the Midwest is generally >95% (Table 1). However, we now know that our earlier conclusion was incorrect because QoI resistant populations exist in potato production areas where QoI fungicides have been used infrequently over the past 8 years (Pasche and Gudmestad 2007). In most of these instances, growers either did not apply a QoI fungicide to their crop or made only one or two applications per year since they first became available in 1999. For example, the frequency of resistance in Western potato production areas of Idaho, Washington, and Oregon varies from 12% to 60% of the population despite infrequent QoI fungicide use and low disease pressure (Table 1). This strongly suggests that the selection pressure QoI fungicides place on the *A. solani* population is so high that F129L mutant populations can develop readily. This is a hard lesson learned by the potato industry—one that should be considered thoughtfully in other agricultural commodities.

## Summary

The development of fungicide resistance in a pathogen is a costly venture. Fungicide resistance means the loss of a valu-

able tool to manage diseases important to producers and it also means a loss of sales for basic manufacturers of agricultural chemicals. The management of fungicide resistance is difficult but not impossible to achieve. Agricultural producers need to be cognizant of indiscriminate use of specific fungicide chemistries, and they should not use a fungicide in isolation. It is important to use multiple methods to manage disease and not to rely on a single disease management tactic, such as a single fungicide chemistry. Finally, methods to monitor important fungal pathogens must be in place in order to detect fungicide-resistant populations before they become widespread. This requires coordination and the cooperation of agricultural producers, state agricultural professionals, and basic manufacturers.

## References


Pasche, J.S., and N.C. Gudmestad. 2007. Prevalence, competitive fitness and impact of the F129L mutation in *Alternaria solani* from the United States. *Crop Protection* (in press). DOI:10.1016/j.cropro.2007.07.011.

Pasche, J.S., L.M. Piche, and N.C. Gudmestad. 2005. Effect of the F129L mutation in *Alternaria solani* on fungicides affecting mitochondrial respiration. *Plant Disease* 89:269–278.

Pasche, J.S., C.M. Wharam, and N.C. Gudmestad. 2004. Shift in sensitivity of *Alternaria solani* in response to QoI fungicides. *Plant Disease* 88:181–187.

# Glyphosate-Resistant Weeds: Yes It Can Happen, Even When You Think You Know How to Kill Weeds

*Bill Johnson, Vince Davis, and Andy Westhoven*

Development of herbicide-resistant weed populations results from overdependence on a specific herbicide mode of action. Target site-based triazine or ALS-inhibitor resistance in weeds is expressed at high levels in plants, which usually means that field use rates will have little or no effect on resistant plants while susceptible plants will be killed. Thus, it is usually fairly obvious when these types of resistant populations develop in a field; as a result, the use of specific products becomes obsolete in controlling the specific herbicide-resistant weed. However, glyphosate resistance is typically expressed at much lower levels and, in many instances, poor application techniques or low rates are considered the primary cause of poor weed control with glyphosate.

However, detailed greenhouse and field investigations by university researchers across the United States. have shown that there are indeed a number of weeds that have evolved low levels of glyphosate resistance (GR), and we can no longer blame poor application techniques on all cases of poor weed control with glyphosate.

The purpose of this presentation is to showcase field history and weed control practices in Indiana production fields that lead to the development of glyphosate-resistant horseweed (aka marestail), giant ragweed, and glyphosate-tolerant common lambsquarters biotypes. We will also show that some weed biotypes that have evolved low levels of resistance show various degrees of injury by glyphosate but can recover and produce viable seed. In addition, we will the review the economic implications of these weeds in the event that glyphosate and glyphosate + ALS–resistant biotypes are present in a specific field, or if multiple weed species develop resistance to glyphosate in a specific field. We will focus specifically on soybeans, because there more herbicide options to manage these glyphosate-resistant species in corn than in soybeans.

Glyphosate-resistant horseweed has been documented in most midwestern states that grow soybeans and corn. The first documented case of glyphosate-resistant horseweed was in Delaware following 2 years of exclusive glyphosate use for preplant and in-crop weed control in glyphosate-resistant soybeans. In Indiana, glyphosate-resistant horseweed was first noticed in southeast Indiana, where continuous soybeans are grown more frequently than in other parts of the state.

On our main glyphosate-resistant horseweed research site, horseweed, which shows a sixfold level of resistance, was documented in 2003. The history of this field was a no-till corn–soybean rotation with conventional (nonglyphosate) herbicide programs used for postemergence weed control from 1996 to 1999. In 2000, GR soybeans were grown for the first time, and glyphosate was used for burndown and postemergence weed control. In 2001, glyphosate was used for the burndown treatment prior to no-till corn establishment, and conventional herbicides were used for postemergence weed control. No-till GR soybeans were then grown in both 2002 and 2003, with glyphosate used as the burndown and postemergence treatments in both years. Thus, there were a total of five glyphosate applications over a 3-year period prior to the evolution of GR horseweed at that site.

Horseweed is not considered to be highly competitive, but it can affect soybean establishment, yields, and harvest. Several options exist to manage glyphosate-resistant horseweed in soybeans. The additional cost to control horseweed prior to planting can be relatively low for 2,4-D ($2/A) or moderately expensive with Gramoxone plus Sencor ($13/A).

However, horseweed with multiple-resistance can evolve. Several counties in Indiana and Ohio have horseweed that is

resistant to both glyphosate and ALS-inhibiting herbicides such as FirstRate and Classic, which limits that option when growers wish to avoid the plant-back time restrictions with preplant applications of 2,4-D or use a tankmix partner with glyphosate after soybeans emerge. When multiple-resistant (glyphosate and ALS) horseweed exists, 2,4-D or Gramoxone are basically the only preplant herbicide options to control existing plants other than tillage; other in-crop postemergence soybean herbicides are not effective.

Giant ragweed is one of the most competitive weeds in the Midwest and is a challenge to control even in Roundup Ready crops. Glyphosate-resistant biotypes have been recently confirmed in Ohio and Indiana giant ragweed populations, and ALS-inhibitor resistance has been reported in several states.

In the first Indiana population that was documented to be glyphosate resistant, the field history included glyphosate-resistant soybeans the last 8 out of 9 years with at least one or two postemergence glyphosate applications. Giant ragweed is currently managed with burndown glyphosate applications plus one or two in-season glyphosate applications. With evolved glyphosate resistance, PPO- and ALS-inhibitor herbicides become the principal options. However, there is a strong likelihood that multiple resistance to glyphosate plus ALS-inhibitor herbicides will evolve, leaving PPO-inhibiting herbicides as the primary remaining option, given that preemergence herbicide options often do not provide adequate control.

Although multiple herbicide resistance increases the challenge to manage specific weed species, the potential also exists for multiple glyphosate-resistant weed species in the same field. Glyphosate-resistant horseweed and giant ragweed have been confirmed in one field where a glyphosate-"tolerant" common lambsquarters is also being investigated. The history of this field included use of nontransgenic corn (i.e., no glyphosate use in corn) and glyphosate-resistant soybeans in a 1:1 rotation. The soybeans were grown without tillage and two to three glyphosate applications were made during the soybean growing seasons for weed control.

The soybean weed management program of this field will now require the grower to use a soil-applied residual herbicide for common lambsquarters control plus 2,4-D to control existing giant ragweed and horseweed, followed by higher rates of glyphosate postemergence to effectively protect yield. The presence of two glyphosate-resistant weeds and glyphosate-tolerant common lambsquarters resulted in weed control expenses that increased from $18/A to $37/A.

# Insecticide Resistance in Western Corn Rootworms: What Can We Learn from Previous Mistakes?

*Blair D. Siegfried, Lance J. Meinke, and Haichuan Wang*

The western corn rootworm, *Diabrotica virgifera virgifera* LeConte (Coleoptera: Chrysomelidae), is arguably the single most important pest of field corn, *Zea mays* L., throughout most of the U.S. Corn Belt, both in terms of crop losses and the use of synthetic insecticides (Levine and Oloumi-Sadeghi 1991; Sappington et al. 2006). Managing corn rootworm populations to minimize risk of economic loss is extremely difficult, in part because of its nearly unlimited capacity to evolve resistance both to chemical insecticides (Metcalf 1986; Meinke et al. 1998; Siegfried et al. 2004; Parimi et al. 2006) and cultural control practices such as crop rotation (Levine et al. 2002). Recent management practices have relied extensively on neurotoxic and nonspecific synthetic insecticides that are directed against both larvae and adults. Corn rootworm management strategies that include prescriptive insecticide applications have not been widely adopted (Gray and Steffey 1995), placing increased pressure on the limited number of options available to growers.

Novel control techniques are being developed and marketed for corn rootworm management. The two most recent and significant developments involve transgenic corn hybrids expressing insecticidal genes from *Bacillus thuringiensis* (Bt) and seed treatments employing neonicotinoid insecticides. Both technologies have the potential to drastically reduce the environmental and human health risks associated with conventional rootworm management practices (e.g., soil insecticides). However, the remarkable history of western corn rootworm adaptation to the selective pressures imposed by recent pest management practices necessitates the proactive implementation of management strategies designed to sustain these novel management alternatives. Moreover, because of the invasive nature of this pest, proactive intervention for the purposes of mitigating invasions or minimizing the spread of resistance outbreaks is critical to future management decisions.

Pesticide resistance management can be defined as the effort to delay or prevent adaptation in pest species to pesticides by preserving the genes that confer susceptibility in pest populations. Several theories have been advanced for managing insect resistance, but few experimental data on their comparative utility are available. In many instances, resistance management decisions rely on poorly validated assumptions of important parameters related to resistance inheritance and population genetic structure of pest species. Mathematical models provide a means to compare the durability of insecticides or transgenic toxins under different patterns of use (varying temporal vs. spatial patchworks, sequential use of toxins vs toxin mosaics, etc.) and to determine the optimal size and placement of "refuges" to minimize selection by the toxins in question. While resistance management strategies based on a set of models have an excellent chance of working provided the genetic assumptions are satisfied, efforts to develop management strategies based on incomplete or incorrect biological data are inherently risky.

In the case of the western corn rootworm, there are a number of striking examples of how this species has evolved resistance that can be tracked both temporally and spatially using diagnostic insecticide bioassays and a number of different biochemical and genetic markers. Information gained from study of these resistance outbreaks provides a unique opportunity to better understand population response to selection pressures, movement of resistance-conferring genes, and fitness costs of resistance, all of which ultimately will lead to improved resistance management recommendations for novel control strategies.

## Examples of Resistance Evolution

### CYCLODIENE RESISTANCE

Cyclodiene insecticides were commonly used as soil treatments for the control of both western and northern corn rootworms from the late 1940s to early 1960s. Benzene hexachloride (Muma et al. 1949), aldrin, chlordane (Ball and Hill 1953), and heptachlor (Ball and Roselle 1954) were the recommended active ingredients for control of root-feeding larvae during this period. Control failures with these compounds were first noted in Nebraska in 1959 (Roselle et al. 1959), and further evaluations in 1960 (Roselle et al. 1960) and 1961 (Roselle et al. 1961) revealed the magnitude and rapid development of the resistance. During 1961, western corn rootworm adults were collected from different fields in Nebraska, and susceptibility to aldrin and heptachlor was determined by topical application (Ball and Weekman 1962, 1963). Differences in susceptibility among field populations provided the first direct evidence of resistance evolution.

The development of cyclodiene resistance coincided with a rapid eastward range expansion. By 1980 the distribution of *D. v. virgifera* covered most of the U.S. Corn Belt, including areas where cyclodienes were not widely used as soil insecticides (Metcalf 1983). Resistance has persisted in populations for many years after the use of these compounds was discontinued (Siegfried and Mullin 1989), even in areas where the insecticides were not commonly used as soil insecticides. Parimi et al. (2006) reported the presence of high levels of resistance in both the laboratory-reared and field-collected adult western corn rootworms based on topical bioassays with the cyclodiene insecticide, aldrin. Aldrin resistance apparently has remained consistently high among field populations over the four decades since resistance was first reported. These high resistance levels have persisted in spite of reduced selective pressures since the cyclodiene insecticides were banned in 1972. However, considerable variation in resistance levels among populations has been detected. A general decline in resistance among Nebraska populations and consistently higher levels of resistance in more eastern populations were noted (Figure 1) based on survival at a diagnostic concentration of the cyclodiene insecticide, aldrin. The general trend for higher resistance levels among populations where selection pressures are believed to have been lowest is puzzling. The use of broadcast applications of cyclodiene insecticides was generally confined to the western Corn Belt where resistance was first identified, and the higher resistance levels in eastern North America seem counter to the geographic gradient in selection intensity.

The only population examined to exhibit what appears to be complete susceptibility to aldrin was a nondiapause laboratory strain that was established from field collections in 1968. This strain was derived from a field collection made in an area where resistance was reported to have been present at the time of collection (Metcalf 1983). Because up to four generations of the nondiapause strain can be reared in the laboratory in a single year, slight fitness disadvantages may have been manifested in the loss of resistance over a shorter period of time relative to field populations. It should also be noted that the nondiapause population has likely undergone a rather restrictive genetic bottleneck during selection for the nondiapause trait. Therefore, in selecting for a nondiapause trait, the genes conferring resistance may have been lost and the susceptibility observed in this strain, unrelated to possible fitness disadvantages.

In most other insect species studied, resistance involves a form of nerve insensitivity caused by a conserved point mutation (ffrench-Constant et al. 2000) in the gene encoding the receptor for the inhibitory neurotransmitter, γ-aminobutyric acid (GABA). Significant progress has been made recently in two specific areas related to cyclodiene resistance in western corn rootworms: (1) identification of the same point mutation in the GABA receptor associated with cyclodiene resistance and (2) identification of significant variation in susceptibility to the cyclodiene insecticide aldrin among

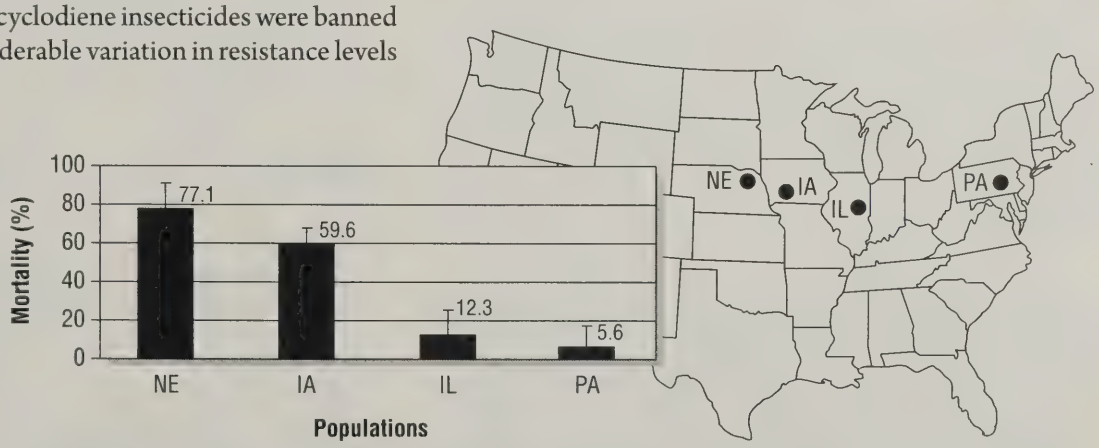


**FIGURE 1 • Susceptibility of *D. v. virgifera* adults collected from Nebraska, Iowa, Illinois, and Pennsylvania to a diagnostic concentration of aldrin corresponding to the $LC_{99}$ of the susceptible nondiapause strain.**

western corn rootworm populations. Because of the rapid range expansion and persistence of cyclodiene resistance in *D. v. virgifera*, detectable variation in susceptibility and availability of molecular markers, cyclodiene resistance in this species represents a potentially important model for understanding the evolution and movement of target site–mediated resistance genes. The identification of molecular markers that are diagnostic for specific resistance genotypes should provide an important tool for clarifying the number of origins of resistance-associated mutations for determining the population genetic structure of invading populations and for refining decisions regarding resistance management and mitigation recommendations. Moreover, because cyclodiene resistance has persisted among rootworm populations for over 40 years, understanding the impact of resistance on reproductive fitness in the presence and absence of selective pressures will be particularly insightful.

## ORGANOPHOSPHATE RESISTANCE

Organophosphate and carbamate insecticides were introduced following the failure of cyclodienes and successfully replaced these compounds as the predominant soil insecticides throughout the U.S. Corn Belt. Both organophosphates and carbamates are still used as soil insecticides and as foliar insecticides in adult management programs. Both soil insecticides and adult rootworm management were adopted as primary management tools where irrigated, continuous corn is planted over large acreages throughout the Platte River valley of central Nebraska. However, in some areas of Nebraska, aerially applied Penncap-M® (methyl parathion) was used almost exclusively (Meinke 1995) over relatively large areas and in consecutive years.

Control failures of aerially applied methyl-parathion were first reported in the early 1990s, and resistance to organophosphate and carbamate active ingredients was documented in rootworm adults from a number of Nebraska populations (Meinke et al. 1998). The distribution of resistant rootworms was initially restricted to areas of the state where adult management had been practiced in excess of ten years, while areas relying on soil insecticides and crop rotation apparently remained susceptible.

In 1996, a diagnostic bioassay was developed for quickly assessing the resistance status of field-collected rootworm populations. Based on the dose response curves of representative resistant and susceptible populations, a diagnostic concentration corresponding to the $LC_{99}$ of a standard susceptible colony was determined. This concentration was used to assess the resistance by identifying the proportion of a given population that exceeds 1% survival at $LC_{99}$ for a susceptible population. Based on sampling results over a 4-year period using the diagnostic concentration of methyl-parathion, resistance exhibited significant expansion both in distribution and in intensity (Figure 2). Initial sampling of rootworm susceptibility in 1996 indicated the presence of two distinct resistant areas based on the presence of susceptible populations that separate these two regions. However, by 1998, significantly increased levels of tolerance were observed in the areas of York and Hamilton counties, and areas previously identified as being susceptible had become highly resistant (Adams County, Figure 2). Although resistance appears to have grown both in intensity and in geographic range, there were still populations of rootworms that remain susceptible to methyl-parathion in proximity to resistant populations. Furthermore, in areas where aerially applied methyl-parathion no longer provides effective control of adult rootworms, growers are adopting other management practices, such as crop rotation and use of soil insecticides.

Importantly, the development and spread of methyl-parathion resistance provides an important tool in validating models of resistance evolution. This approach was recently used to validate a stochastic model of the evolution of resistance to adulticidal sprays of methyl-parathion in western corn rootworm populations in Nebraska (Caprio et al. 2006). When resistance was examined as a genetic phenomenon, the rate of increase of the resistance allele depended almost entirely on genetic factors ($LC_{50}$ values), the characteristics of the pesticide (residual activity), and the variance associated with emergence of adults. When resistance was measured as failure of methyl-parathion to reduce populations below threshold levels (0.5 gravid females per plant), parameters

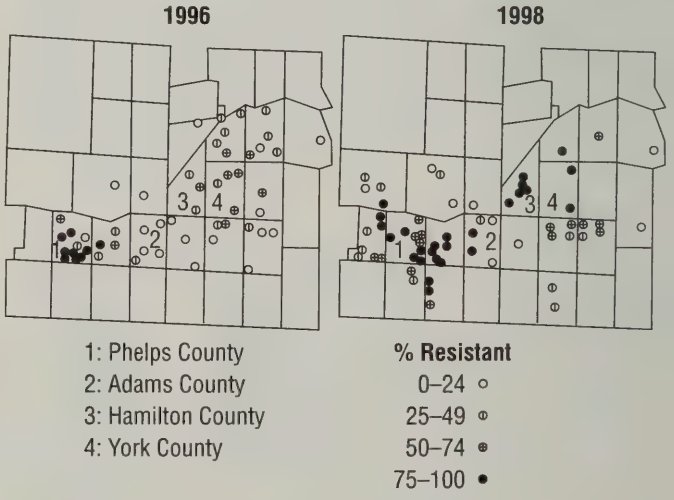


**FIGURE 2 • Distribution of methyl-parathion–resistant western corn rootworms based on percentage of survival at diagnostic concentration after 4-hour exposure; N = 50–100.**

that contributed to population growth rate (mortality and fecundity) were also important. These data suggest two important phases in resistance evolution in corn rootworms: (1) a genetic phase associated with negative growth rates and rapid changes in resistance allele frequencies and (2) a rebound phase associated with positive growth rates and near fixation of the resistance allele.

## What Can We Learn?

For transgenic crops expressing the Bt toxin, current resistance management recommendations favor combining a high dose of insecticidal protein with a refuge of nontransgenic plants (Roush 1996; Andow and Hutchison 1998; ILSI 1998; Bates et al. 2005). Theoretically, the high dose kills all heterozygous individuals (i.e., resistance is functionally recessive) and constrains the frequency of resistance alleles to a low level (Roush and Daly 1990; Gould 1998; USEPA 1998). The purpose of a refuge is to supply susceptible, nonselected individuals to the general population. The use of a refuge strategy should increase the probability that rare, homozygous-resistant individuals will mate with homozygous-susceptible individuals. These matings will produce only heterozygous progeny that can be eliminated by the high-dose plants (Roush 1996). This strategy relies on several assumptions regarding the genetic architecture of resistance that are difficult to validate. Utilizing the information that is available from previous resistance events provides an important opportunity to limit the uncertainty that is inherent to some of these assumptions. Specifically, understanding the population response to selective pressures, fitness costs associated with resistance, and movement of resistance-conferring alleles are all important to the design and implementation of resistance management and mitigation strategies. Given the western corn rootworm's remarkable history of resistance evolution to both chemical and cultural control tactics, the implementation of sound resistance management programs is critical to its sustainable management.

## References


Andow, D.A., and W.D. Hutchison. 1998. Bt-corn resistance management, pp. 19–66. In M. Mellon and J. Rissler (eds.). *Now or Never: Serious New Plans to Save a Natural Pest Control.* Union of Concerned Scientists, Cambridge, MA.

Ball, H.J., and R.E. Hill. 1953. You can control corn rootworm. *Nebraska Experiment Station Quarterly,* Winter 1952–53, Nebraska Agriculture Experiment Station, Lincoln, NE.

Ball, H.J., and R.E. Roselle. 1954. *You Can Control Corn Rootworm.* University of Nebraska. Extension Circular 1567. University of Nebraska, Lincoln, NE.

Ball, H.J., and G.T. Weekman. 1962. Insecticide resistance in the adult western corn rootworm in Nebraska. *Journal of Economic Entomology* 55:439–441.

Ball, H.J., and G.T. Weekman. 1963. Differential resistance of corn rootworms to insecticides in Nebraska and adjoining states. *Journal of Economic Entomology* 56:553–555.

Bates, S.L., J.-Z. Zhao, R.T. Roush, and A.M. Shelton. 2005. Insect resistance management in GM crops: Past, present and future. *Nature Biotechnology* 23(1):57–62.

Caprio, M.J., T.J. Nowatzki, B.D. Siegfried, L.J. Meinke, R.J. Wright, and L.D. Chandler. 2006. Assessing the risk of resistance to aerial applications of methyl-parathion in the western corn rootworm (Coleoptera: Chrysomelidae). *Journal of Economic Entomology* 99:483–493.

ffrench-Constant, R.H., N. Anthony, K. Aronstein, T. Rocheleau, and G. Stilwell. 2000. Cyclodiene resistance: From molecular to population genetics. *Annual Review of Entomology* 48:449–466.

Gould, F. 1998. Sustainability of transgenic insecticidal cultivars: Integrating pest genetics and ecology. *Annual Review of Entomology* 43:701–726.

Gray, M.E., and K.L. Steffey. 1995. On-farm validation of Pherocon AM trap utility for corn rootworms (Coleoptera: Chrysomelidae): Outlook for producer acceptance in Illinois. *Journal of Sustainable Agriculture* 7:121–134.

International Life Sciences Institute and Health and Environmental Sciences (ILSI). 1998. *Evaluation of Insect Resistance Management in Bt Field Corn: A Science-Based Framework for Risk Assessment and Risk Management: Report of an Expert Panel.* ILSI Press, Washington, DC.

Levine, E., and H. Oloumi-Sadeghi. 1991. Management of diabroticite rootworms in corn. *Annual Review of Entomology* 36: 229–255.

Levine, E., J.L. Spencer, S.A. Isard, D.W. Onstad, and M.E. Gray. 2002. Adaptation of the western corn rootworm, *Diabrotica virgifera virgifera* LeConte (Coleoptera: Chrysomelidae) to crop rotation: Evolution of a new strain in response to a cultural management practice. *American Entomologist* 48:94–107.

Meinke, L.J. 1995. *Adult Corn Rootworm Management.* MP63-C, Agricultural Research Division, Institute of Agriculture and Natural Resources. University of Nebraska, Lincoln, NE.

Meinke, L.J., B.D. Siegfried, R.J. Wright, and L.D. Chandler. 1998. Adult susceptibility of Nebraska western corn rootworm (Coleoptera: Chrysomelidae) populations to selected insecticides. *Journal of Economic Entomology* 91:594–600.

Metcalf, R.L. 1983. Implications and prognosis of resistance to insecticides, pp. 703–733. In G.P. Georghiou and T. Saito (eds.). *Pest Resistance to Pesticides.* Plenum, New York, NY.

Metcalf, R.L. 1986. Foreword, pp. vii–xv. In J.L. Krysan and T.A. Miller (eds.). *Methods for the Study of Pest* Diabrotica. Springer-Verlag, New York, NY. 260 pp.

Muma, M.H., R.E. Hill, and E. Hixson. 1949. Soil treatments for corn rootworm control. *Journal of Economic Entomology* 42:822–824.

Parimi, S., L.J. Meinke, B.W. French, L.D. Chandler, and B.D. Siegfried. 2006. Stability and persistence of aldrin and methyl-parathion resistance in western corn rootworm populations (Coleoptera: Chrysomelidae). *Crop Protection* 25:269–274.

Roselle, R.E., L.W. Anderson, and P.W. Bergman. 1961. *Annual Report for 1961, Cooperative Extension Work in Entomology, Lincoln, Nebraska.* University of Nebraska, Lincoln, NE.

Roselle, R.E., L.W. Anderson, R.G. Simpson, and P.W. Bergman. 1960. *Annual Report for 1960, Cooperative Extension Work in Entomology, Lincoln, Nebraska.* University of Nebraska, Lincoln, NE.

Roselle, R.E., L.W. Anderson, R.G. Simpson, and M.C. Webb. 1959. *Annual Report for 1959, Cooperative Extension Work in Entomology, Lincoln, Nebraska.* University of Nebraska, Lincoln, NE.

Roush, R.T. 1996. Can we slow adaptation by pests to insect resistant transgenic crops?, pp. 243–263. In G.J. Persley (ed.). *Biotechnology and Integrated Pest Management.* University Press, Cambridge, England.

Roush, R.T., and J.C. Daly. 1990. The role of population genetics in resistance research and management, pp. 97–152. In R.T. Roush and B.E. Tabashnik (eds.). *Pesticide Resistance in Arthropods.* Chapman and Hall, New York, NY.

Sappington, T.W., B.D. Siegfried, and T. Guillemaud. 2006. Coordinated *Diabrotica* genetics research: Accelerating progress on an urgent insect pest problem. *American Entomologist* 52:90–97.

Siegfried, B.D., and C.A. Mullin. 1989. Influence of alternative host plant feeding on aldrin susceptibility and detoxification enzymes in western and northern corn rootworms. *Pesticide Biochemistry and Physiology* 35:155–164.

Siegfried, B.D., L.J. Meinke, S. Parimi, M.E. Scharf, T.J. Nowatzki, X. Zhou, and L.D. Chandler. 2004. Monitoring western corn rootworm (Coleoptera: Chrysomelidae) susceptibility to carbaryl and cucurbitacin baits in the areawide management pilot program. *Journal of Economic Entomology* 97:1726–1733.

U.S. Environmental Protection Agency (EPA). 1998. Scientific Advisory Panel, Subpanel on *Bacillus thuringiensis* (Bt) Plant-Pesticides and Resistance Management, February 9–10, 1998 (Docket Number: OPP 00231).

# Insect Resistance Management (IRM) Requirements in Bt Crops

*Scott Baucum*

The Monsanto Commercial Trait Stewardship Team holds primary implementation responsibility for insect resistance management (IRM) education, monitoring for compliance, remediation, and enforcement related to the conditional registrations of Monsanto's insect-protected seed traits.

Monsanto meets these objectives with attention to the Monsanto pledge and the Biotechnology Industry Organization's "Excellence Through Stewardship" commitment.

## IRM

Maintaining product conditional registrations for insect protection traits requires annual monitoring and reporting to EPA. Metrics include

- on-farm assessments where farmers and, in Monsanto's case, an independent third party sit down with the farmer to discuss corn and/or cotton seed planting for the current year and compare them to the planting options available to farmers under the end-user licensing agreement (EULA).
- phone-market research to determine the percentage of compliance.
- grower point of sale (GPOS) reporting to track each sale to named growers. Annual EPA reporting also includes details related to education efforts, complaint management, and enforcement actions such as dealer or grower license actions that remove product access from noncompliant parties. EPA requires continuing product registration on Monsanto's performance of these tasks and grower and dealer compliance. Monsanto, like other trait registrants, reports this information to the Ag Biotech Stewardship Technical Committee (ABSTC) for compilation into one single report submitted to EPA the final week of January each year.

Monsanto reports the following information to ABSTC:

- total units of insect-protected seed sold and not returned, by county, by grower, and licensed by 7/31
- results from on-farm assessments
  - 250 Bollgard/Bollgard II cotton
  - 700 YieldGard Corn Borer
  - 200 YieldGard Corn Rootworm
  - 300 YieldGard Plus
- a list of stewardship education and training materials used to train growers and dealers
- results of annual grower phone survey
- details for refuge violations

Monsanto recently commissioned market research to determine what could be done to preserve IRM compliance. The results were clear. Self-discipline initiatives can be expected to yield little, if any, increase in compliance. On the other hand, farmers indicated that communicating consequences for noncompliance could improve compliance, provided that awareness of these consequences was broad and certain. The problem with a private company communicating "consequences" to customers is obvious. At Monsanto, we separate these responsibilities from the sales and marketing groups and involve independent third parties, when possible, to retain all possible integrity in our commitment to stewardship excellence.

Similar reasoning supports the necessity for industry standards across brands for stewardship integrity. Without industry standards and similar company commitment to those standards, stewardship can become a competitive disadvantage to those who "hold the line" versus those who manage issues with a "wink and a "nod," and it is in these critical seconds when a farmer will take his or her lead from those given charge to set the right example.

Likewise, working together, we can best determine the least disruptive path to achieve our mutually important goals. Our farmers deserve the very best we can give them in regard to keeping any "regulation" as minimally invasive as possible while still accomplishing its intended protection.

Many people sacrifice now to save money in a 401(k) with an expectation of benefits later. People discipline themselves now to eat in moderation and to exercise with an expectation of greater health over a longer time period. It is important to follow this same sense of delayed gratification to preserve the benefits of these important technologies.

# Increasing Corn Acres and Prophylactic Use of Bt Hybrids: Implications for IPM and IRM

*Michael E. Gray and David W. Onstad*

At a conference in Winnipeg, Manitoba (March 25–28, 2007), some members of the North Central Branch of the Entomological Society of America grappled with a controversial topic at a symposium titled "The Future of IPM in Corn and Soybean Production."

Is it surprising that this question is being debated? Is it startling that the very question of IPM implementation, or the lack thereof, in the corn and soybean agroecosystem is being discussed among academics? Will those engaged in large-scale commercial production of corn and soybeans look back on the 2007 growing season as a year in which the principles of IPM were followed, or largely ignored? Is IPM relevant in 2008? Most of us engaged in commercial agriculture seem to have our own interpretation of what these three letters represent.

There are many formal definitions of IPM. A definition (Rabb 1972) used many times is as follows: "Pest management is the intelligent selection and use of pest-control actions that will ensure favorable economic, ecological, and sociological consequences." Another definition is provided by Geier (1966):

> (1) determining how the life system of a pest needs to be modified to reduce its numbers to tolerable levels, that is, below the economic threshold; (2) applying biological knowledge and current technology to achieve the desired modification, that is, applied ecology; and (3) devising procedures for pest control suited to current technology and compatible with economic and environmental quality aspects, that is, economic and social acceptance.

Many participants who took part in the Winnipeg symposium agreed that a relatively easy case can be made that the use of Bt hybrids and herbicide-tolerant crops leads in most instances to favorable economic returns. Additionally, the use of transgenic crops has led to reductions in pesticide use and presumably improved environmental consequences and human health and safety.

With regard to "sociological" consequences—the last component of Rabb's IPM definition—those of us in the IPM community continue to struggle with how to adequately describe the changing sociological forces across the agricultural landscape and how to enhance IPM implementation. It seems certain that maximizing crop production inputs does not equate to IPM. Some of the sociological forces (Gray and Steffey 2007) that are shaping how IPM decisions are being made in the corn and soybean production systems include

- surging interest and investment in biofuels
- favorable commodity prices
- significant increase in continuous corn acres
- escalating demand for triple-stacked corn hybrids (even in areas where corn rootworms and European corn borers do not represent a persistent economic threat)
- use of insecticidal seed treatments (neonicotinoids: clothianidin and thiamethoxam) on every kernel of Bt seed
- increasing interest in the use of fungicides on corn, in many instances through a prophylactic approach
- concern about inadequate refuge deployment
- increasing reliance on a restricted spectrum of herbicides in corn and soybeans
- larger farms
- fewer farmers, more absentee landowners

- an increasingly trait-driven marketplace
- a paradigm shift from IPM to IRM (insect resistance management)

Against this backdrop of factors, the principles of integrated pest management in the corn and soybean agroecosystem are increasingly being ignored. Of particular concern is the lack of integration of pest management tactics and the over-reliance on single-tactic approaches without any scouting input. Some of the very costly and unpleasant outcomes associated with pesticide misuse are being forgotten. What are some examples of these unwanted consequences (Gray and Steffey 2007)?

- insecticide resistance
- secondary pest resurgence
- harmful effects against nontarget insects and other organisms
- potentially harmful pesticide residues on food products
- pesticide movement into our natural resources, such as ground and surface water

In a report released on July 5, 2007, titled *Adoption of Genetically Engineered Crops in the United States* (www.ers.usda.gov/Data/BiotechCrops), the USDA Economic Research Service revealed the significant escalation in use of Bt corn in Illinois and other states. In 2006, 19% of all planted corn in Illinois was characterized as a "stacked gene" variety. In 2007, the use of stacked corn hybrids in Illinois more than doubled and is estimated to be at 40% of planted corn acres. In 2006, 55% of corn planted in Illinois was estimated to be a genetically engineered hybrid (Bt only, herbicide-tolerant only, or stacked gene variety). In 2007, that percentage has increased to 74%. Therefore, roughly three-quarters of corn acreage in Illinois during the most recent growing season was planted to a genetically engineered corn hybrid. Adoption of this technology is occurring at a remarkable pace. What percentage of the corn produced in Illinois during 2008 will rely on a stacked gene hybrid?

Why is there any concern about the escalating use of Bt hybrids for insect control? Why is there any debate regarding whether the use of Bt hybrids should be considered within an IPM framework? After all, don't Bt hybrids fall into the host plant resistance category of pest management tactics?

The easy answer to the last question is "yes." Our primary concern is that the "I" in IPM is largely being ignored. Where is the integration of management tactics? Even the cultural management approach of crop rotation for western corn rootworm control broke down after a few decades.

In recent years, there has been a proliferation of journal articles about the development of simulation models that seek to predict the longevity of transgenic crops based on a variety of biological, genetic, and ecological assumptions.

The remaining portion of this paper focuses on the predictions of one journal article published last year (Crowder et al. 2006). One has to be cautious in interpreting these models because they are built on many assumptions that may later be proven inaccurate. Nonetheless, they are helpful in assessing the potential for resistance development to Bt in a very complicated agricultural landscape.

In addition, through modeling analyses, we can begin to see where more biological and ecological research is required to improve our predictions of Bt longevity.

The Crowder et al. (2006) paper offers some interesting projections regarding the potential development of western corn rootworm resistance to transgenic corn. The landscape simulated with this model included 100% continuous corn and a nonvariant western corn rootworm population. Interestingly, the results of the simulation (assuming R, the allele for resistance to transgenic Bt corn, is recessive) did not vary that much with respect to toxin dose (high, medium, or low). Unlike Bt hybrids engineered for European corn borer control, transgenic hybrids that offer protection against corn rootworms are not high-dose events.

In the simulation model, the durability of transgenic corn (15 years or more) was not greatly affected by the type of management strategy selected (assuming R, the allele for resistance to transgenic Bt corn, is recessive): "(1) planting 80% transgenic corn to the continuous cornfield each season, (2) planting transgenic corn based on sampling and economic thresholds along with a 20% refuge, (3) planting 100% transgenic corn to the continuous cornfield each season, and (4) planting transgenic corn based on sampling and economic thresholds without refuges."

Based on the results of this simulation model, if the western corn rootworm allele for resistance to transgenic corn is recessive, we can expect long-term durability of the Bt technology (15 years or more before the allele for resistance reaches 50% among the western corn rootworm population), regardless of the four management strategies employed. If the allele (R) for resistance to transgenic Bt corn among western corn rootworms is partially recessive and the toxin dose is characterized as medium, the durability of transgenic hybrids is quite short, only 5 to 6 years, regardless of the management strategy (1–4) described previously.

If low-dose transgenic Bt hybrids are used, and the allele (R) for resistance to transgenic Bt corn is partially recessive, then the longevity of these transgenic hybrids can be improved

to 9 to 10 years. If the allele (R) for resistance is dominant among western corn rootworms, it reaches 50% within the population very quickly (~5 years), even with refuges.

The authors (David W. Crowder, David W. Onstad, and Michael E. Gray) of the paper made the following concluding statements:

> The use of economic thresholds slightly slowed the evolution of resistance to transgenic insecticidal crops. In areas with or without rotation-resistant western corn rootworm phenotypes, the use of sampling and economic thresholds generated similar returns compared with strategies of planting transgenic corn, *Zea mays* L., every season. Because transgenic crops are extremely effective, farmers may be inclined to plant transgenic crops every season rather than implementing costly and time-consuming sampling protocols.

Although the durability of transgenic Bt corn for western corn rootworms was not affected significantly (assuming the resistance allele is recessive) by the use of any of the management strategies used in this simulation model and described previously, the fact that many Bt hybrids that will be planted in 2008 will be "stacked" places a special emphasis on the deployment of 20% refuges as required by the U.S. Environmental Protection Agency. Maintaining the viability of the refuge to delay or prevent resistance to Bt by European corn borers is essential. The IRM strategy of using a high-dose event along with a refuge has worked exceptionally well for more than a decade in preventing the development of resistance by European corn borers. We are concerned that some producers will ignore the use of the refuge this spring. If this behavior begins to occur on a more regular basis, resistance will develop, and we risk the loss of a very valuable pest management tool.

The Crowder et al. (2006) paper has similar elements with the Foster et al. (1986) journal article about the use of soil insecticides in continuous corn production systems. The authors of the Foster et al. (1986) paper offered the following concluding statement: "The optimal strategy for managing corn rootworms in Iowa in our study was not to sample for adults and always to treat corn following corn with a soil insecticide at planting time."

To date, resistance development has not occurred with the granular soil insecticides despite the fact that they have been commonly used for decades. However, it must be mentioned that producers have been unwittingly deploying "refuges" between corn rows due to the application of granular soil insecticides in a band or in-furrow at planting.

Because the four management strategies described by Crowder et al. (2006) seemed to have relatively little impact on the speed at which resistance development to Bt corn occurred within the western corn rootworm population, some may argue against the need for a refuge. Because of the escalating use of stacked Bt hybrids, this would be a serious mistake. If Bt hybrids (nonstacked) are deployed only for corn rootworms, the value of sampling, thresholds, and use of refuges to delay the onset of resistance will continue to be debated among academics. The authors of the Crowder et al. (2006) article offered the following cautionary statement with regard to their simulation model:

> The application of these results is limited by several assumptions in the model. First, we assumed that a very simple genetic system is responsible for evolution of the behavioral changes and rotation resistance. Second, we assumed that all farms are the same in a homogeneous region or that areawide pest management is occurring. Third, we did not include costs of sampling or uncertainty because of sampling error, unlike Nyrop et al. (1986). Changes in these assumptions could have produced other outcomes.

The results of this simulation model reinforce our concern about the lack of integration of pest management tactics in the current corn and soybean production system. As we begin to move in the direction of pyramiding genes with different modes of action in transgenic hybrids for insect resistance management purposes, several questions surface:

- Will integration of management tactics in the field be replaced with the insertion of a diverse array of genes with transgenic crops for insect control?
- Will the use of refuges for resistance management purposes be necessary over the long haul as we begin to utilize more transgenic crops with a different internal arsenal of genes effective against a wide array of insect pests?
- How long will the use of scouting, economic thresholds, and economic injury levels continue to be relevant in large-scale commercial cornfields for many insect pests?
- Will producers increasingly make their most important pest management decisions in the fall and winter months as they evaluate the transgenic seed opportunities before them?

## References

Crowder, D.W., D.W. Onstad, and M.E. Gray. 2006. Planting transgenic insecticidal corn based on economic thresholds: Consequences for integrated pest management and insect resistance management. *Journal of Economic Entomology* 99(3):899–907.

Foster, R.E., J.J. Tollefson, J.P. Nyrop, and G.L. Hein. 1986. Value of adult corn rootworm (Coleoptera: Chrysomelidae) population estimates in pest management decision making. *Journal of Economic Entomology* 79:303–310.

Geier, P.W. 1966. Management of insect pests. *Annual Review of Entomology* 11:471–490.

Gray, M., and K. Steffey. 2007. Maximizing crop production inputs does not equate to integrated pest management. In *the Bulletin*, no. 8, May 18. www.ipm.uiuc.edu/bulletin/article.php?id=717. University of Illinois, Urbana-Champaign.

Nyrop, J.P., R.E. Foster, and D.W. Onstad. 1986. Value of sample information in pest control decision making. *Journal of Economic Entomology* 79:1421–1429.

Rabb, R.L. 1972. Principles and concepts of pest management, pp. 6-29. In *Implementing Practical Pest Management Strategies, Proceedings of a National Extension Pest-Management Workshop*. Purdue University, Lafayette, IN.

# Managing the Consequences of Long-Term Weed Control

*Aaron G. Hager*

Plant species considered to be weeds have caused myriad maladies to befall human society since the beginning of recorded time, including hunger caused by losses in crop productivity and yield, dramatic reductions in the aesthetic value of countless landscapes, significant and sometimes permanent loss of ecological diversity, physical ailments of humans and livestock alike, and untold expenditures of financial resources aimed toward their control. Yet, despite man's best efforts to keep these undesirable plants in check, weeds continue to plague multiple aspects of daily life.

Those who are considered weed management practitioners of agronomic cropping systems know all too well how difficult it can be to remove weeds from the cropping landscape. History is replete with examples of how weeds have evolved and evaded many of the tools designed for their management. Previous papers in this conference's proceedings have illustrated some of these adaptations, including changes in the emergence characteristics of giant ragweed (once considered an early-emerging species) in response to long-term crop production practices; increased occurrence of weed species (such as hophornbeam copperleaf) not previously well characterized; and selection of herbicide-resistant biotypes of species sensitive to a particular herbicide (such as waterhemp with resistance to three herbicide modes of action).

Some of these adaptations could perhaps be described as being analogous to corn yield potential—many plant genes and environmental factors contribute to the observed response. Other adaptations in weeds are the result of our intense selection for traits that ensure survival of the species in the "artificial" environment of agronomic cropping systems. For example, waterhemp was once very sensitive to many ALS-inhibiting herbicides but now demonstrates high-level resistance via an altered herbicide target site selected by repeated use of these herbicides. Some weeds have even adapted to the age-old practice of hand weeding; intense hand weeding of flooded rice fields has selected for a barnyardgrass biotype that closely mimics rice in appearance and thus escapes being hand weeded from the crop.

The examples previously described illustrate how weed species have adapted to changes in production practices. In some instances, weeds adapt in response to a single selection factor. Other times, the adaptation is due to multiple changes in production practices. Whether single or multiple factors are involved, it is important to remember that weeds will continue to adapt and challenge us.

The introduction and commercialization of glyphosate-resistant soybean varieties and corn hybrids has, in many ways, dramatically altered the weed management practices of farmers across much of the Midwest. Estimates place the adoption of herbicide-resistant soybean varieties and corn hybrids (principally glyphosate resistant) at approximately 90% and 37%, respectively, of the U.S. soybean and corn acreage, according to the USDA National Agricultural Statistics Service Report, June 2006.

Glyphosate-resistant crops offer many advantages to farmers, but as the previous examples illustrate, over-reliance on a single management option can lead to new weed management challenges.

Figure 1 illustrates the worldwide "history" of herbicide-resistant weeds. Until 2007, glyphosate-resistant weeds were the least represented herbicide-resistant biotypes among all major herbicide mode-of-action families. In 2007, the frequency of glyphosate-resistant weed biotypes surpassed the frequency of dinitroaniline-resistant weed biotypes.

A "philosophical" consideration sometimes discussed among academic weed scientists is the difference (real or perceived)

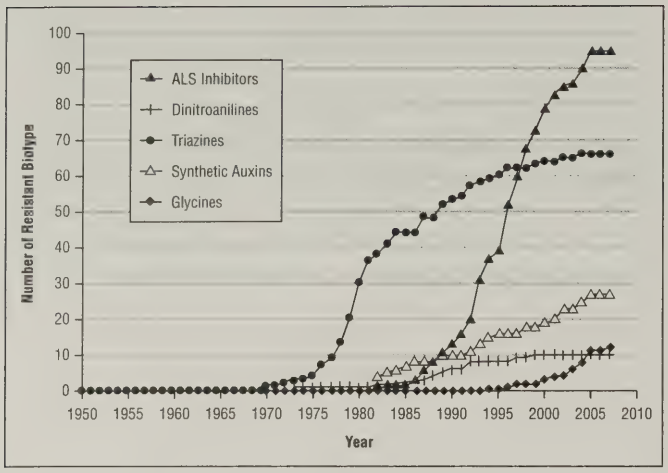


**FIGURE 1 • The worldwide occurrence of herbicide-resistant weed biotypes, presented by herbicide family.**

between what is accomplished through weed *management* compared with weed *control*. The weed science community has no "Webster's of Weed Science Terminology" from which to seek definitive answers, so debate often becomes spirited, and conjectures abound among pontificators. The great writer and author Merriam Webster offers several possible ways to define the terms *control* and *management*. Careful scrutiny and (biased) selection of possible definitions provide the following:

- *control*: to reduce the incidence or severity of, especially to innocuous levels
- *manage*: to handle or direct with a degree of skill

The weed spectrum in many Illinois soybean fields today is such that a singular control strategy (e.g., a single postemergence herbicide application) may not always provide consistent control. Over the past decade, many practitioners have become very proficient at controlling weeds, but perhaps less proficient at managing weeds. Potentially serious repercussions are poised to plague Illinois soybean farmers in 2008 due to the widespread adoption of *weed control* in lieu of *weed management*. A specific consequence of widespread weed control is the selection of Illinois waterhemp biotypes resistant to glyphosate.

A pertinent question to consider is, how will Illinois soybean farmers manage a waterhemp population that may no longer be susceptible to glyphosate or diphenylether herbicides, the only postemergence soybean herbicide options that control waterhemp?

Weed scientists at the University of Illinois have conducted field, greenhouse, and laboratory research with an Illinois waterhemp population that is not controlled at field-use rates of glyphosate-containing products. Although evidence to date suggests this *particular* population is in fact resistant to glyphosate, it is altogether likely that other populations of glyphosate-resistant waterhemp exist within Illinois. Indeed, anecdotal reports in 2007 suggested that glyphosate-resistant waterhemp may be present in several fields, ranging from counties in southeast Illinois to west-central Illinois. Observations suggested putative glyphosate-resistant waterhemp populations were more prevalent in soybeans than corn, but there is scant reason to believe these biotypes were not present in the 2007 Illinois corn crop.

The following recommendations are suggested for management of herbicide-resistant waterhemp in the 2008 soybean crop. Many of the 2007 soybean acres will be rotated to corn in 2008, so a relevant consideration is whether glyphosate-resistant waterhemp will be more *problematic* in 2008 or 2009 (when the 2007 soybean fields return to soybeans). Regardless, we assume that glyphosate-resistant and PPO-resistant waterhemp biotypes will be encountered across a large geographical area of central and south-central Illinois during 2008. Additionally, it is altogether possible that waterhemp biotypes resistant to both glyphosate and PPO inhibitors soon will be discovered. These biotypes represent a worst-case scenario, in that there are *no postemergence herbicide options for their control in soybean.*

The suggested recommendations for 2008 soybeans (these assume glyphosate-resistant soybeans) are listed. The considerations and justifications employed to develop these recommendations are based on recent and previous research on waterhemp biology and management:

1. Apply a full labeled rate (according to label guidelines for soil type and organic matter content) of a soil-residual herbicide no sooner than 7 days before planting or later than 3 days after planting.
2. The initial postemergence application of glyphosate alone at 0.75 to 1.0 pounds a.e. must occur when waterhemp is 3 to 5 inches tall.
3. Fields *must* be scouted 7 days after the initial glyphosate application to determine treatment effectiveness.
4. If waterhemp control is inadequate and retreatment is necessary, apply a PPO-inhibiting herbicide (lactofen, fomesafen, or acifluorfen) at a full labeled rate as soon as possible.
5. Rescout the treated field within 10 to 14 days to determine effectiveness of the PPO-inhibiting herbicide treatment. If scouting suggests some treated plants might survive, implement whatever tactics are available or feasible to

rogue these surviving plants from the field *before* they reach a reproductive growth stage.

These recommendations are, in reality, an illustration of the need for an integrated approach to waterhemp management. Integrated weed management introduces multiple tactics to control weeds and slow the rate at which weeds are able to adapt to a single control tactic. Introducing an integrated weed management approach into glyphosate-resistant cropping systems may well stave off some potential new challenges, enhancing the long-term effectiveness of this valuable weed control strategy.

Is an ounce of prevention worth a pound of cure?

# Fungicides on Disease-Free Corn: The Case from 2007

*Emerson D. Nafziger*

Spurred by the high price of corn and by sales campaigns to sell foliar fungicides as a way to improve "plant health" in a preemptive manner, as many as 3 to 4 million, or 25% to 35%, of the corn acres in Illinois were sprayed with strobilurin fungicides in 2007. Many producers committed to having fungicide applied weeks or months before planting, with the understanding that if they did not sign up early there might be no way to get such applications made in time. As a result of this demand, dozens of spray aircraft from outside of Illinois were brought into the state in June and July.

The start of the season was generally good, with timely planting in most areas. May was warm and dry, with good early corn growth and good stands. The dry weather continued past the middle of June, with 79% of the topsoil rated as "short" or "very short" by June 17 (NASS). With above-normal rainfall the last third of June, that dropped to less than 20% by July 1. The corn crop went from showing moderate to severe symptoms of water stress in mid-June into a period of very rapid growth in late June and early July. As a result, by July 1 the crop was 66 inches tall on average, and about one-third of it was silked.

Faced with a rapidly developing crop and a narrow application window to get fungicides applied by tasseling, applicators in many areas started early, often before the tassels had emerged. Those applying fungicide by ground also started early in order to be able to spray corn before it got too tall. With such rapid growth (statewide, corn grew at an average rate of 2 inches per day during the second half of June), spraying fungicide before tassel emergence was not off-label in most cases; in fact, spraying fungicide on seed corn fields before tasseling is a common practice.

Although there was some foliar disease (primarily gray leaf spot) at the time of fungicide application, the dry weather through mid-June had not provided much opportunity for inoculum to build up, and the incidence of foliar disease was low to zero in most fields at the time of fungicide application. This lack of disease did not cause much alarm, or apparently much cancellation of application, probably because fungicide application had been promoted as a way to improve yields even when disease incidence is low. With high prices and a corn crop that was shaping up to be good to excellent, most producers were eager to invest in what they considered to be yield-increasing input.

## Damage from Fungicide

Within a month after application, some producers noticed that ear development was not normal in some fields that had been sprayed with fungicide. Such abnormal development has more than a single cause, but in some cases unsprayed strips showed none of the damage that sprayed areas showed, making it clear that fungicide (or additives) was the primary cause.

Damage took the form of ears whose development seems to have been interrupted at about the time the developing ear was 1 to 1.5 inches long, with some of the terminal portion of the ear showing no silk or kernel development. It appeared as if the fungicide had stopped growth in the developing ear at a very precise time, with older tissue escaping damage and younger tissue arrested instantly. Evidence for this includes the fact that timing of application was a critical factor: Plants sprayed before ears shoots had cleared the leaf sheath in some cases developed no ears at all, while those sprayed after silking had begun often showed no symptoms. Fields

sprayed by ground showed symptoms more often, probably because they had been sprayed earlier, before they reached full height, and also because they usually had more spray volume used—hence, better coverage.

Even though damage from fungicide application in 2007 was unexpected, we had seen some hints in earlier work that suggested that such damage might be possible. We saw very similar damage following pre-tassel fungicide application in several irrigated fields in northern Illinois in 2006. Also, in a year study of effects of Headline fungicide timing on corn, we found a significant yield loss in 2 out of 3 years when the fungicide was applied at the 14-leaf stage, or about a week before tasseling. This loss was about 8% to 10% and occurred only at that timing.

Even though the losses from fungicide application were unexpected and in some fields serious, I consider it likely that the growing and weather conditions were a critical factor in this damage in 2007. There were fields not sprayed with fungicide where similar damage occurred, suggesting that the 2007 crop was just vulnerable to disturbances in ear development. There were some reports of damage on seed corn in 2007, even though many seed fields get sprayed routinely, and such damage, if specific to the pre-tassel stage of application, would have become evident years ago. The fact that labels did not restrict application to tasseling or later suggests that companies who developed and who sell strobilurin fungicide had seen little such damage in the past.

While the loss in yield due to fungicide application in some fields in 2007 was unfortunate and costly, we should probably see such damage as more of a fluke than as something that we should expect to see often. It will be relatively simple to change labels to restrict application to tasseling or later, which should largely rule out such damage in the future. Because damage was more related to ear development than to tassel development, it might be appropriate to relate the beginning of application to ear stage rather than to tassel stage.

## What Did Fungicide Deliver When There Wasn't Damage?

The majority of fields sprayed with foliar fungicide in 2007 did not experience damage. At the same time, as noted above, they also did not have much, if any, foliar disease at the time the decision was made to spray. Did the promise of greater yield from better "plant health" materialize, and did fungicide application in 2007 provide a good return on investment?

We conducted a series of fungicide studies in several locations in Illinois in 2007. In most cases, fungicides produced either no yield response or the response was not adequate to cover the cost of the material plus application (Table 1). We are here estimating material plus application (by air) to equal the value of 6 bushels of corn (at $3.50 per bushel, $21 per acre). Two of the trials included rotation as a variable,

**TABLE 1 • Results from Headline fungicide trials on corn in Illinois, 2007.**

| | | | Grain yield (bu/A) | | | |
|---|---|---|---|---|---|---|
| Location | Trial also included | Previous crop | Without Headline | With 6 oz Headline | Increase from Headline | Did it pay? |
| DeKalb | N rate | Soybean | 218 | 228 | 9* | Yes |
| Monmouth | N rate, rotation | Soybean | 237 | 238 | 2 | No |
| | | Corn | 203 | 206 | 3 | No |
| Monmouth | | Soybean | 185 | 188 | 3* | No |
| Urbana | Fertilizer, population | Corn | 194 | 207 | 13* | Yes |
| Urbana | N rate | Soybean | 203 | 198 | –4 | No |
| Urbana | Planting date, population | Soybean | 219 | 218 | –1 | No |
| Perry | Tillage, fertilizer, population | Corn | 193 | 195 | 1 | No |
| Perry | N rate, rotation | Soybean | 133 | 135 | 3 | No |
| | | Corn | 142 | 141 | –1 | No |

*Indicated significant difference at the 10% error level (*P*).

and results are given for both corn following corn and corn following soybean in these trials.

In none of the trials reported in Table 1 were foliar diseases severe, except at DeKalb, where untreated plots had about 20% incidence. Fungicide reduced this by about two-thirds. In the Monmouth trial, where fungicide increased yield by 3 bushels following soybeans, foliar disease was decreased from about 8% to 2% by fungicide. Hence, fungicide was generally effective in reducing incidence of foliar disease where it occurred.

In eight of the ten trials, there was either no yield increase or, if one existed, it was inadequate to pay for the treatment. In the two trials where yield was increased enough to produce a profit from fungicide application, one was corn following corn and one was corn following soybeans. On average, application of fungicide over these trials increased yield by 3 bushels per acre, only half enough to pay for the treatment.

These results show that, in a year when there was little foliar disease at the time of fungicide application and when conditions are such that diseases do not become a major factor, the use of foliar fungicide seldom returned its cost. Given that the purported physiological effect of strobilurin fungicide in plants is to reduce respiration and possibly to decrease yield-limiting hormone levels, it also seems likely that good conditions at pollination, which were the rule in Illinois in 2007, reduced the likelihood of a positive yield response unrelated to disease control.

# Fungicides: Do They Adversely Affect Beneficial Insect Pathogens in Multiple Cropping Systems?

*David W. Ragsdale and Karrie A. Koch*

A wide variety of fungi are pathogenic to insects and mites—some 700 species have been described (Hajek and St. Leger 1994). Often, these entomopathogens are key regulators of arthropod populations, and they are particularly important in regulation of twospotted spider mites and aphids in a variety of crops. Most studies that focus on these pathogens also conclude that manipulation of entomopathogen populations is at best difficult. In part, this is because the environmental conditions that favor fungal germination must be met for an epizootic to occur. However, this does not mean that we should ignore the contribution of these insect pathogens in regulation of insect and mite populations. One of the underlying principles in IPM is to be aware of production practices that will conserve beneficial organisms.

It is a common misconception that fungal epizootics only occur when insect or mite populations are very high—at densities well above where plant injury will occur. These spectacular epizootics are easy to observe; this casual observation often leads to the mistaken conclusion that fungal pathogens arrive too late to be reliable control agents. While it is more difficult to observe the role fungal pathogens play in population regulation at lower insect and mite densities, they indeed are active at low host density. So, although we may not be able to stimulate an epizootic to occur, we should avoid farming practices that will disrupt these important, naturally occurring insect pathogens.

This article reviews cropping systems where this disruption has been documented, demonstrates the current research being conducted in Minnesota on the impact of fungicides on the entomopathogenic fungi found attacking soybean aphids, and provides a general understanding of why, in IPM, a pesticide should be used only when a specific pest is being targeted—one of the fundamental principles of a sound integrated pest management (IPM) program.

## Biology of Entomopathogenic Fungi

Insect pathology has a long history, dating back to 2700 B.C., when diseased silkworms were first described in China (Tanada and Kaya 1993). However, the systematic study of insect pathology was not begun until much later—after the germ theory of disease was proposed. The first textbook devoted to the subject of insect pathology wasn't published until 1949 (Steinhaus 1949). The first insect pathogen to be associated with a disease was a fungus associated with silkworms, and this pathogen that Agostino Bassi first worked with was later named *Beauveria bassiana* in his honor (Steinhaus 1956). We would suggest that anyone reading the proceedings of this conference has benefited from the work of early pioneers in insect pathology. The discovery of *Bacillus thuringiensis* and its role in control of corn rootworm and European corn borer has its roots in insect pathology.

Entomopathogenic fungi are found in all four recognized phyla of fungi (Figure 1): Basidiomycota (mushroom and rust), Ascomycota (cup or sac fungi), Zygomycota (zygospores formed from the fusion of two hyphae), and Chytridiomycota (microscopic fungi with motile zoospores) (Roberts and Yendol 1971; Alexopoulos et al. 1996). A large number of fungi representing some 15,000 species are currently in a group that no longer has any systematic standing, the deuteromycetes. This group of asexually reproducing fungi have in the past been called the "Fungi Imperfecti" or "asexual fungi." Molecular studies often reveal that these asexual fungi are the conidial or asexual stage of a species assigned to the Ascomycota or, in some cases, to the Basidiomycota. Some

of the better-known insect pathogens are known only from their asexual stage, including *B. bassiana.*

Many of these deuteromycetes can grow on simple artificial media, their spores are relatively stable, they are common inhabitants of soil, spore dispersal is generally by wind, infection occurs when a droplet of water containing viable spores lands on an insect's integument, and the rather thick-walled spores remain viable for long periods of time under adverse conditions.

In general, insect pathogenic fungi currently assigned to the deuteromycetes are less species specific than species found in the Zygomycota. Insect pathogens such as *B. bassiana* and *Lecanicillium lecanii* (formerly *Verticillium lecanii* (Zimm.), *Paecilomyces fumosoroseus,* and *Metarhizium anisopliae* are commonly produced and marketed as bioinsecticides (Table 1). These bioinsecticides are not typically used in major row crops because the cost of producing these fungi is too high, as are the costs associated with registering products for use in the United States. However, these bioinsecticides do play a vital role in organic agriculture, greenhouse production systems (flower, fruit, and vegetables), and other high-value production systems where chemical residues are unwanted or not tolerated.

## The Entomophthorales

The focus of this paper is on the naturally occurring insect pathogens in the order Entomophthorales (phylum Zygomycota, class Zygomycetes; see Figure 1). The order Entomophthorales comprises fungal species that are obligate insect and mite pathogens—they are not known to propagate on other organic matter (i.e., they are not saprophytic but rather strictly pathogenic to arthropods). Entomophthorales are often unable to grow on simple media and either require highly enriched media or cannot be cultured at all. Many of these fungal species are involved in the population regulation of aphids and twospotted spider mites in major row crops (corn, soybean, cotton, wheat, sorghum, sunflower, potato).

A unique character of the Zygomycota is that these fungi produce a zygospore, which is a "thick-walled resting spore" (Alexopoulos et al. 1996) formed by the fusion of two specialized structures (gametangia) from two compatible strains into a zygospore. Although production of a zygospore is the defining characteristic of the members of the class Zygomycetes, some species in this class are not known to produce zygospores; thus, other relevant characters are used to place the species within the class (Alexopoulos et al. 1996).

The Entomophthorales are a unique order within the class Zygomycetes and produce conidia as their infective propagules instead of sporangiospores, which are produced by all other Zygomycetes (Alexopoulos et al. 1996). In general, species within the Entomophthorales produce fewer spores than their insect pathogenic counterparts in the deuteromycetes, such as *B. bassiana.* Spores of the Entomophthorales are forcibly ejected from the conidiophore, which is unique to the order Entomophthorales (Alexopoulos et al. 1996). Although spores can be found in the air, and wind-dispersed spores are key to developing an epizootic (Steinkraus et al. 1999), in general, spores of Entomophthorales are less important in dispersal than are infected alate aphids (Feng et al. 2004). In China, movement of insect pathogenic fungi over large distances (miles) is likely accomplished by infected winged aphids dispersing the pathogen rather than by passive dispersal of liberated spores (Feng et al. 2004).

Species identification within the Entomophthorales is accomplished by staining the primary conidia to visualize the number and placement of nuclei, along with the overall size and shape of the spore. Primary conidia often have special mucilaginous material that allows the spore to either adhere to nearby leaf surfaces or to attach to insect exoskeletons (Figure 2). Under favorable environmental conditions—typically high humidity and moderate temperatures—spores absorb water from the environment and germinate. It is during this germination phase

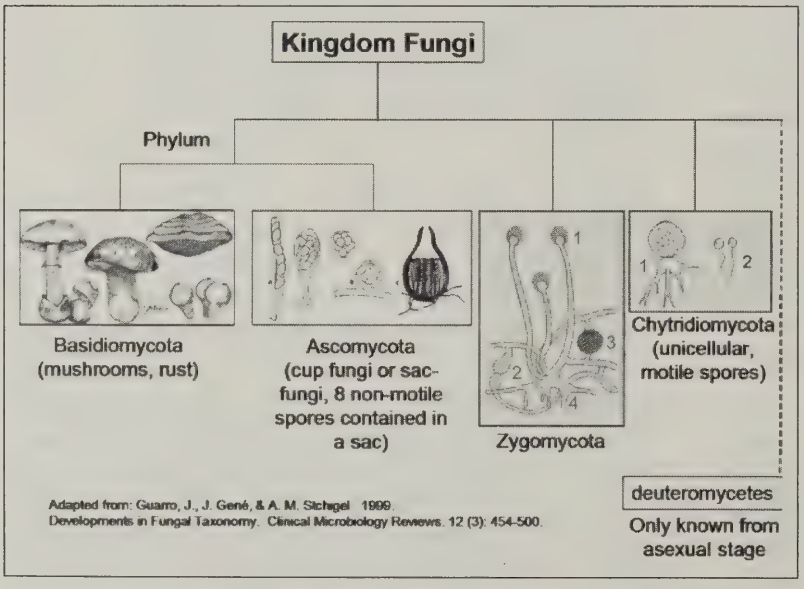


**FIGURE 1 • Fungal systematics using the fungal tree of life phylogeny.**

**TABLE 1 • Bioinsecticides derived from live fungi (spore suspension).** Data from U.S. EPA and NPIRS Web sites, October 2007.

| Product name | Manufacturer | Fungal species and strain | Target insect/mite |
|---|---|---|---|
| Naturalis-L | Troy Biosciences | *Beauveria bassiana* ATCC74040 | whiteflies, weevils, aphids, thrips, leaf-feeding caterpillars, Colorado potato beetles, mites, white grubs, chinch bugs, ants, and mole crickets |
| Mycotrol ES, Botanigard ES Botanigard 22WP Mycotrol O | Laverlam International Corp. | *Beauveria bassiana* GHA, ABG-6178 | whiteflies, thrips, aphids, psyllids, mealybugs, scarab beetles, plant bugs, and weevils |
| BioVL* | Sundaram | *Verticillium lecanii* | Sucking insects |
| Vertisoft* | Agriland Biotech, Ltd. | *Verticillium lecanii* | Sucking insects |
| PFR-97 20% WDG | Certis U.S.A., LLC | *Paecilomyces fumosoroseus* | whiteflies, aphids, thrips, and spider mites |

*Product not available for use in the United States.

that fungicides are most likely interfering with the infection process.

A different type of secondary conidia, a conidium borne on a long, thin stalk called a capilliconidium (Figure 3), can be formed by certain species of Entomophthorales (Alexopoulos et al. 1996). This type of secondary conidia has the ability to adhere to chitin and may be formed to increase the chance of contact with a susceptible host or with an individual that can transport the spore to a susceptible individual (Alexopoulos et al. 1996).

Most Entomophthorales overwinter in the soil profile via resting spores—thick-walled spores that typically must undergo a cold temperature treatment before they germinate. However, one of the most common aphid-infecting pathogens, *Pandora neoaphidis*, does not form resting spores and either overwinters as hyphal bodies or conidia within the cadaver of the aphid (Feng et al. 1992; Nielsen et al. 2003). Thus, the Entomophthorales are a unique and interesting group of fungi, yet much of their biology and ecology remains unexplored.

Once an insect pathogenic fungus kills its host, fungal growth switches from vegetative to reproductive, during which time rhizoids (structures that secure cadavers to a substrate), conidiophores, and conidia are formed externally on the insect cadaver (Alexopoulos et al. 1996). Once conidia are released from the conidiophores, if environmental conditions are suitable, they will germinate. If the spore lands on a susceptible host, a germ tube will form, penetrating the insect cuticle. A typical life cycle is illustrated in Figure 4.

**FIGURE 2 • Scanning electron micrograph (SEM) image of a spore of *Conidiobolus obscurus* attached to the leg of a green peach aphid, *Myzus persicae*.** Photo by A. Lagnaoui.

If a suitable host is not available, fungi may continue to produce smaller secondary conidia, and even smaller tertiary conidia may be formed and so on until all energy is depleted (Alexopoulos et al. 1996). Once the germ tube penetrates into the insect hemocoel, yeastlike hyphal bodies are produced and, in the process of vegetative growth inside their insect host, nutrients are absorbed, toxins are produced, and death of the host occurs quickly—typically in a matter of a few days (Tanada and Kaya 1993). Conidia are then again formed, and the process of sporulating spreads the disease. An epizootic can proceed rapidly when insects are at high

density, and a remarkably rapid decline in insect or mite density can be observed.

In general, host specificity is greater with the Entomophthorales, and some isolates of the same species will not easily infect other closely related insect species. *Pandora neoaphidis* is frequently isolated from a variety of aphids, but strains of these pathogens exist, and not all strains or isolates can infect all aphid species. For example, an isolate of *P. neoaphidis* we isolated from pea aphid, *Acyrthosiphon pisum* (Harris), was not able to infect soybean aphid, *Aphis glycines*, under controlled laboratory conditions (Koch, unpublished data).

**FIGURE 3 • Capilliconidium of Zoophthora radicans from soybean aphid, *Aphis glycines*. Magnified 400×, stained with aceto-orcein.** Photo by D. Ragsdale.

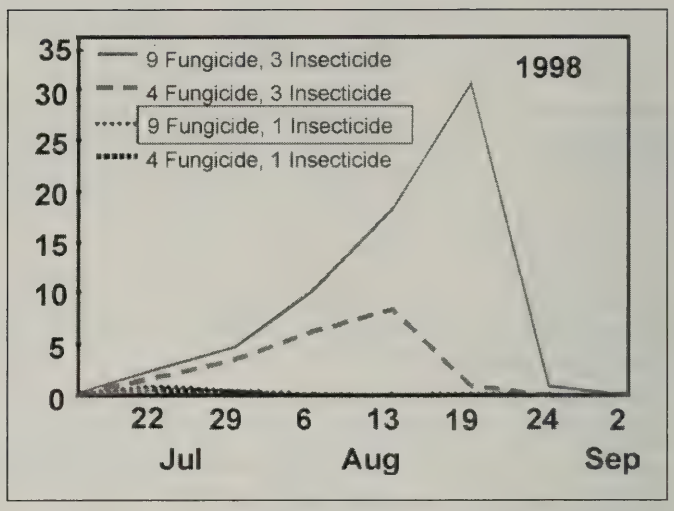


**FIGURE 4 • The response of green peach aphid populations on a per-leaf basis when plots were treated with two fungicide regimes (nine vs. four applications) and two insecticide regimes (one vs. three applications). Insecticides used (esfenvalerates) are for control of insects other than green peach aphid, which is resistant to this pyrethroid.**

## Interference of Fungicide with Entomopathogenic Fungi

It should be no surprise that fungicides applied to plant surfaces to control foliar pathogens might interfere with the infection process of entomopathogens. Indeed, it is well documented in a variety of cropping systems that foliar-applied fungicides are detrimental to the progression of an epizootic, and, at times, insect populations will increase in response to the suppression of entomopathogens (Byrde 1966; Cadatal and Gabriel 1970; Bailiss et al. 1978; Vänninen and Hokkanen 1988; Elkassabany et al. 1992; Smith and Hardee 1993; Majchrowicz and Poprawski 1993; Lagnaoui 1990, Ruano-Rossil et al. 2002).

Other crops where aphid species are commonly regulated by pathogenic fungi include cotton and cotton aphid, *Aphis gossypii* (Steinkraus et al. 1993, 1994, 1995); fava (field) bean and the black bean aphid, *Aphis fabae* Scopoli (Berthelem et al. 1969; Dedryver 1976, 1978; Wilding et al. 1978, 1979; Wilding and Perry 1980); sugar beet and the black bean aphid (Gustafsson 1969); small grains and the complex of grain aphids (Dean and Wilding 1971, 1973; Latteur 1973; Papierok et al. 1984; Latteur and Jansen 2002); and potato and the green peach, *Myzus persicae*, and potato aphid, *Macrosiphum euphorbiae* (Lagnaoui 1990; Ruano-Rossil et al. 2002).

In soybeans it has been documented that multiple fungal species infect soybean aphid (Steinkraus et al. 2002; Nielsen and Hajek 2005). Our research focuses on the extent to which fungicides used to control soybean rust might interfere with these beneficial fungal pathogens of soybean aphid, *Aphis glycines*.

There is a substantial body of literature reporting that pesticides do indeed adversely affect prevalence of entomopathogenic fungi (Byrde 1966; Cadatal and Gabriel 1970; Bailiss et al. 1978; Wilding et al. 1978, 1979; Vänninen and Hokkanen 1988; Lagnaoui 1990; Elkassabany et al. 1992; Majchrowicz and Poprawski 1993; Smith and Hardee 1993). Field studies are often supported by numerous laboratory studies showing that most fungicides, some insecticides, and some herbicides inhibit germination of conidia and growth of mycelia of entomopathogenic fungi (Hall and Dunn 1959; Yendol 1968; Soper et al. 1974; Fritz 1976, 1977; DeLorme and Fritz 1978; Öncüer and Latteur 1979; Wilding and Brobyn 1980; Vänninen and Hokkanen 1988; Lagnaoui 1990; Latteur and Jansen 2002).

We present selected field studies where entomopathogens play a key role in regulating aphid populations and documentation where fungicides adversely affected entomopathogenic fungi.

## Case Studies

### ALFALFA

The important role that fungal pathogens play in regulation of pea aphid populations in alfalfa in Wisconsin was described in great detail by Hutchison and Hogg (1985). They showed through life table studies that accounting for the proportion of *P. neoaphidis*–infected individuals was necessary before their stochastic models would accurately describe aphid population dynamics.

The effect of fungal pathogens was as important as measuring the proportion of the population that was emigrating, and it was far more important than mortality associated with predators or parasitoids. Fungicides are rarely, if ever, used in alfalfa production; thus, the alfalfa agroecosystem is ideal for the study of role entomopathogens play in regulating aphid populations. Plus, the dense canopy allows for microclimates to exist that favor fungal epizootics.

### POTATO

In Minnesota, Nanne and Radcliffe (1971), Lagnaoui (1990), and later Ruano-Rossil et al. (2002) showed that fungicides commonly used in potato production caused a population response (resurgence or flaring) of green peach aphids. Entomopathogens were severely suppressed, and some species of fungi were essentially eliminated when any fungicide was applied (Figure 5).

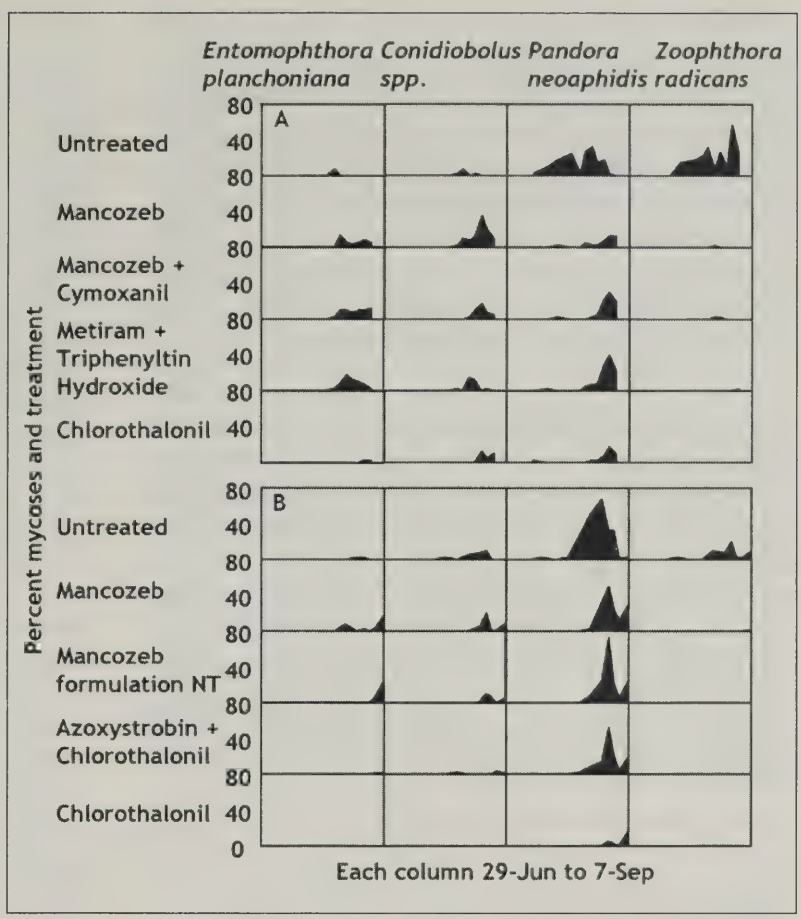


**FIGURE 5 • Prevalence of mycoses by causal species in *Myzus persicae* in response to fungicide treatment regimes: percentage prevalence for Rosemount 1998 (A) and 1999 (B).** *Conidiobolus* spp. = *obscurus, coronatus* (Costantin) Batko, and *thromboides* Drescher.

One caveat, however, is often overlooked in these field experiments. All fungicide treatments were actually made in combination with various insecticides. The insecticides were used to control other insect pests, such as Colorado potato beetle and potato leafhopper, that, if left untreated, would cause severe leaf damage (hopperburn) or result in complete defoliation. The insecticides used were not toxic to green peach or potato aphids. What was not documented was the impact these insecticides might have on predators and parasitoids associated with the potato-colonizing aphids. Nevertheless, plots treated with a combination of fungicide and insecticide resulted in green peach aphid populations that were from 1.7 to 10.0 times greater than the insecticide-only treated control. And fungal-infected aphids were more common (22.4% to 77.5%) in plots treated with insecticide alone, while aphids in plots treated with fungicides plus insecticide had significantly lower disease prevalence (4.0% to 5.2%).

It is unrealistic to expect commercial potato production to occur without the use of fungicides. This became even more apparent in 1993, when a fungicide-resistant strain of *Phytophthora infestans,* the fungus that causes late blight in potato, became established in the United States, which resulted in potato producers using an even more intensive fungicide application program.

Ruano-Rossil et al. (2002) showed that, in general, using two different fungicides, either tank-mixed or applied sequentially, was more detrimental to the entomopathogen complex. Additional work (Ragsdale, unpublished data) confirmed that it was actually the combination of insecticide and fungicide that caused aphid populations to flare in potato production. The use of fungicides alone, even in an intensive program necessary to combat metylaxyl-resistant *P. infestans,* did not cause aphid populations to flare (see Figure 4).

## COTTON

In the mid-South Cotton Belt, the cotton aphid, *Aphis gossypii,* can be a serious pest of cotton. However, the aphid is routinely infected with the fungus *Neozygites fresenii,* one species of entomopathogenic fungus that performs well in the high temperature and high relative humidity found in the mid-South. Research has shown that when more than 15% of the aphid population is infected with this fungus, their population will likely decline. When infection exceeds 30%, progression of the epizootic is almost ensured.

By knowing what proportion a sample of cotton aphids is infected with *N. fresenii,* cotton growers can refrain from making one or more insecticide applications for aphid control. To diagnose whether a sample of cotton aphids is indeed infected requires that aphids be sent to a specialized lab for microscopic analysis. A report is provided to the grower or the crop professional, usually within 24 hours. This "Cotton Aphid Fungus Sampling Service" (Steinkraus 2007) report indicates the level of infection observed and recommends measures to control aphids in that field. This is an example of how knowing the disease prevalence can directly affect the application of insecticides.

The fungicide chlorothalonil was shown to have higher aphid densities, and the epizootic was delayed about 1 week in fungicide-treated plots (Wells et al. 2000); therefore, in the cropping system in this case study, a single application of fungicide interfered with the progression of the epizootic.

## SOYBEANS

Field experiments performed from 2005–2007 in Minnesota showed that the most common soybean aphid pathogen was *Pandora neoaphidis.* Other fungal pathogens isolated included *Conidiobolus thromboides* and *Zoophthora radicans.* In 2005 and 2006 in Lamberton, Minnesota, various fungicide regimes were applied to small soybean plots (Table 2). In 2005, soybean aphid disease prevalence peaked on August 30. Laboratory results found that 31% of apparently healthy aphids in control plots were infected with *P. neoaphidis.* On the same day, prevalence of diseased aphids among fungicide-treated plots was only 3.5% (Figure 6). A similar trend was observed in 2006, but environmental conditions were unfavorable for disease development (hot and dry), and peak prevalence occurred much later in the growing season (September 6), at 4% in the untreated control. Peak prevalence was 2.5% in fungicide-treated plots, which was delayed until September 11. These results confirm that soybean rust fungicides are detrimental to the entomopathogenic fungi that infect soybean aphids under field conditions.

In 2007, we conducted field experiments at our irrigation research center at Becker, Minnesota. We caged single soybean plants, introduced healthy aphids to these cages, and allowed aphid densities to increase in the absence of predation. When aphids were greater than 150 per plant for R2 soybeans and 750 per plant for R5 soybeans, we sprayed plants with water alone (control), a strobilurin fungicide (Headline), or a strobilurin-triazole mix (Headline SBR) of fungicides. Mini-epizootics were created by releasing *Pandora neoaphidis*–infected soybean aphids into the cages. Following the release of *P. neoaphidis*–infected aphids, newly infected aphids were recovered in 50% of the strobilurin-treated plots and 33% of plots treated with a strobilurin-triazole mix, compared to 100% in the control plots (water only) (Figure 7A). This implies that when fungicides are applied prior to the initiation of fungal disease in an aphid population, disease transmission can be significantly reduced.

**TABLE 2 • Fungicide treatments applied to small plots in Lamberton, Minnesota, in 2005. All applications were made at the recommended labeled rate.**

| Treatment | Active ingredients | Product name | Application timing |
|---|---|---|---|
| 1 | Pyraclostrobin + Tebuconazole | Headline SBR | Growth stage R2 |
| | Pyraclostrobin + Tebuconazole | Headline SBR | 14 DAT* |
| 2 | Pyraclostrobin + Tebuconazole | Headline SBR® | Growth stage R2 |
| | Pyraclostrobin + Tebuconazole | Headline SBR® | 14 DAT* |
| | Chlorothalonil | Bravo Weatherstik® | 28 DAT* |
| 3 | Azoxystrobin + Propiconazole | Quilt® | Growth stage R2 |
| | Azoxystrobin + Propiconazole | Quilt® | 14 DAT* |
| 4 | Trifloxystrobin + Propiconazole | Stratego® | Growth stage R5 |

*DAT: Days after application of first treatment.

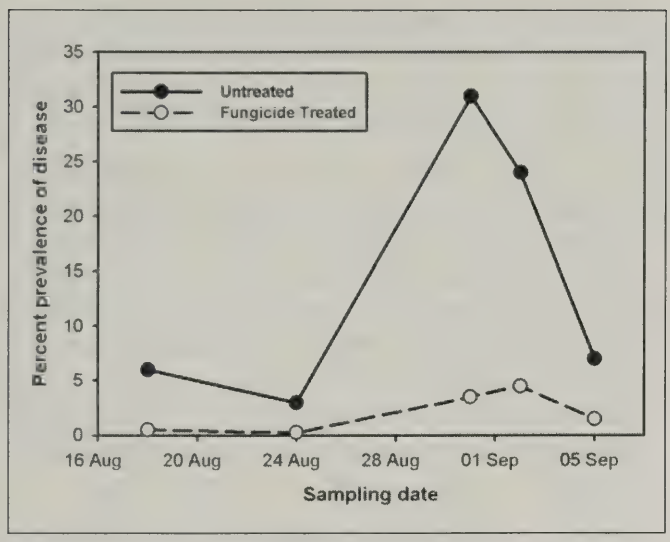


**FIGURE 6 • Percentage prevalence of disease in soybean aphid in untreated (solid line) and fungicide-treated (dashed line) plots in Lamberton, Minnesota, in 2005.** Fungicide treatment lowered the prevalence of disease up to 89% when compared to the untreated control. All fungicides tested were detrimental to entomopathogens; thus, data were combined for clarity.

When the same fungicides were applied approximately 2 weeks after the release of *P. neoaphidis*-infected soybean aphids, recovery of newly infected soybean aphids was again reduced to 83% and 58% for the strobilurin and strobilurin-triazole mix, respectively (Figure 7B). Thus, the inhibition of disease transmission may extend beyond the first several days following application. Because disease epizootics are believed to be initiated by the immigration of infected aphids, this reduction in establishment has the potential to limit or prevent the establishment of disease in the population, especially when abiotic conditions are less than ideal.

During the same experiment, mini-epizootics were initiated and monitored in the single-plant cages twice during the 2007 growing season, when soybeans were in stage R2 and again in R5. Environmental conditions were poor for disease transmission at the R2 plant stage of the experiment; however, overhead irrigation provided adequate moisture that resulted in moderate disease levels. At the disease peak, which occurred 7 days after the release of infected aphids, the mean percentage prevalence of diseased aphids in the plots treated with fungicides was reduced to 21% and 17% of the water-treated control for the strobilurin and strobilurin-triazole mix, respectively.

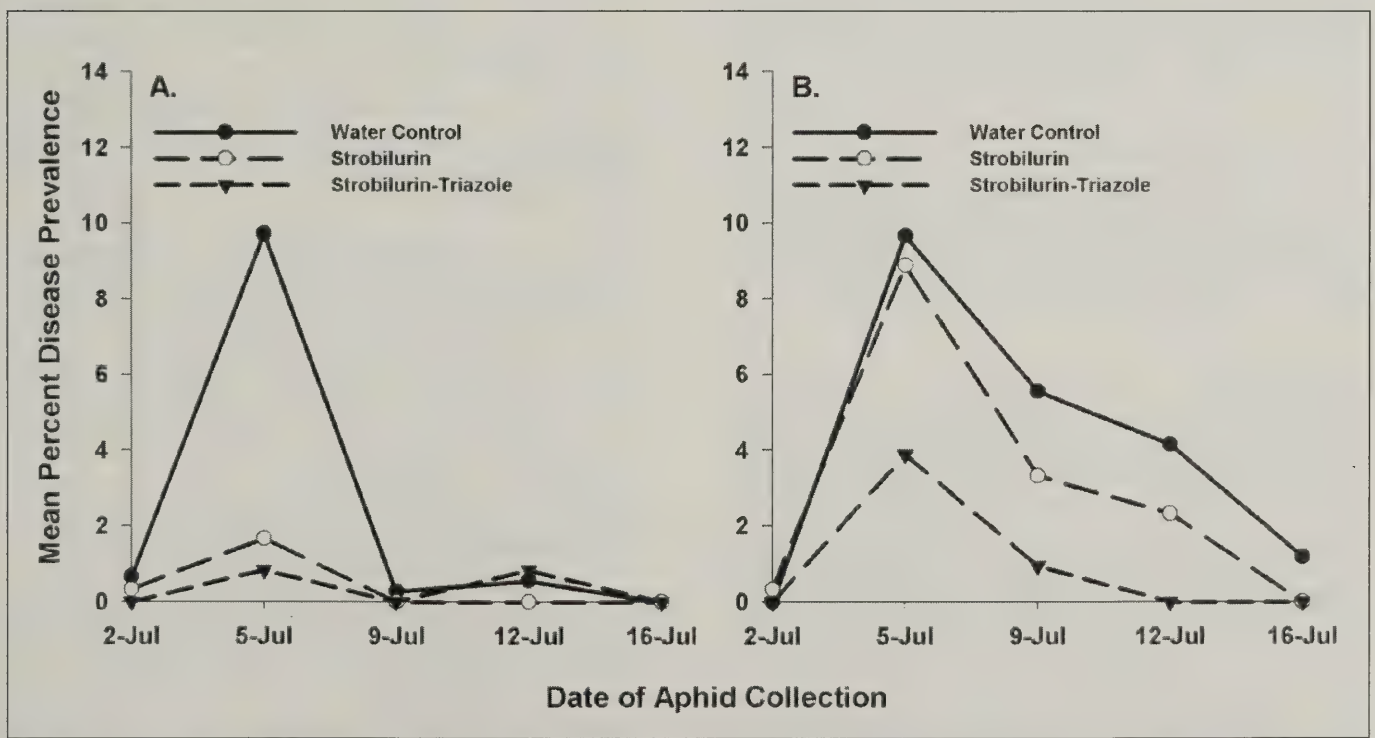


**FIGURE 7 • Percentage prevalence of *Pandora neoaphidis* infection in soybean aphid when fungicide is applied prior to placing diseased aphid inoculum (A) or applying fungicide after inoculum is present (B) in Becker, Minnesota, 2007.**

Environmental conditions changed drastically when the experiment was conducted during $R_5$, which included frequent rainfall, heavy dews, and cooler temperatures. This combination of conditions allowed the fungus to overcome the negative effects of fungicide applications, leading to comparable disease levels among all the treatments. During this time period, newly infected soybean aphids were recovered even from cages in which no inoculum was released. Thus, it appears that the detrimental effects of fungicides can be overcome by *P. neoaphidis* if environmental conditions are favorable for an epizootic to occur. However, it should be noted that the August of 2007 was the wettest August in Minnesota history, so these ideal conditions are unlikely to occur frequently.

In summary, soybean rust fungicides have the potential to diminish the prevalence of fungal disease in field populations of soybean aphid. The negative effects of the fungicides seem to be mitigated by environmental conditions in that warm, dry conditions will prohibit epizootics regardless of the presence of fungicides, and, in overwhelmingly beneficial conditions, the fungi can overcome the detrimental effects of the fungicides. Disease establishment within a population seems to be most strongly decreased when fungicides are applied immediately before inoculum introduction.

The results of these studies will become important as the use of these fungicides increases across the landscape. The highest disease levels have been reported from soybean aphids on their overwintering host, common buckthorn (Nielsen and Hajek 2005), implying that these fungi may play their most important role in aphid regulation during the fall, when the aphids are no longer on soybean. The next step in this research is determining if the negative effects of soybean fungicides can continue to act on these beneficial fungi as they move with the aphids to buckthorn.

## Conclusion

Fungicides clearly can adversely affect the infection cycle of entomopathogenic fungi that are key regulators of key pests of aphids and spider mites in multiple cropping systems. Although environmental conditions are often less than ideal for an epizootic to occur in many cropping systems, infected aphids can nevertheless be isolated under environmental conditions that are not conducive for widespread epizootics.

There is a growing body of literature that has documented detrimental effects associated with fungicide use and reduced prevalence of infected insects. Many tested fungicides have been shown to have a broad spectrum of activity. More recently, a new class of fungicides, the strobilurins, are being used with greater frequency in crop production. The strobilurins have just a single site of activity; as a consequence, these fungicides are often not used by themselves. A partner fungicide that has a different mode of action is recommended or required as part of a resistance management program.

In general, when more than one active ingredient was used, suppression of entomopathogenic fungi was significantly increased. It is not a foregone conclusion that fungicide use will cause an increase in aphid or spider mite populations. However, there are no studies showing that fungicides enhance these beneficial fungi. The safe assumption, when there is lack of information, would be that suppression is likely and, as a general rule, employing any crop protection chemical should be undertaken only when there is a target pest that will result in crop loss in excess of the cost of control.

Application of fungicides for mere "plant health effects" is not sound pest management and could result in disruption of a suite of natural enemies that provides economic control of aphids or spider mites.

## References


Alexopoulos, C.J., C.W. Mims, and M. Blackwell. 1996. *Introductory Mycology*, 4th ed. John Wiley and Sons, New York, NY.

Bailiss, K.W., G.A. Partis, C.J. Hodgson, and E.V. Stone. 1978. Some effects of benomyl and carbendazim on *Aphis fabae* and *Acyrthosiphon pisum* on field bean (*Vicia faba*). *Annals of Applied Biology* 89:443–449.

Berthelem, P., J. Missonnier, and Y. Robert. 1969. Le puceron noir de la fève, *Aphis fabae* Scop. (Hom., Aphididae) et la culture de la féverole de printemps (*Vicia faba* L.). *Annales de Zoologie Écologie Animale* 1:183–196.

Byrde, R.J.W. 1966. The vulnerability of fungus spores to fungicides, pp. 289–297. In M.F. Madelin (ed.). *The Fungus Spore* (Proceedings of the 18th Symposium of the Colston Research Society, University of Bristol). Butterworths, London, UK.

Cadatal, T.D., and B. P. Gabriel. 1970. Effect of chemical pesticides on the development of fungi pathogenic to some rice insects. *Philippine Entomologist* 1:379–395.

Dean, J.W., and N. Wilding. 1971. *Entomophthora* infecting the cereal aphids *Metapolophium dirhodum* and *Sitobion avenae*. *Journal of Invertebrate Pathology* 18:169–176.

Dean, G.J.W., and N. Wilding. 1973. Infection of cereal aphids by the fungus *Entomophthora*. *Annals of Applied Biology* 74:133–138.

Dedryver, C.A. 1976. Évolution comparée des mycoses à *Entomophthora* sur le puceron noir de la fève (*Aphis fabae* Scop.) en cultures de betteraves et de féveroles. *Sciences Agronomiques Rennes* 1976:189–199.

Dedryver, C.A. 1978. Facteurs de limitation des populations d'*Aphis fabae* dans l'Ouest de la France. 3. Répartition et incidence des

différentes espèces d'*Entomophthora* dans les populations. *Entomophaga* 23:137–151.

DeLorme, R., and R. Fritz. 1978. Action de divers fongicides sur le développement d'une mycose à *Entomophthora aphidis*. *Entomophaga* 23:389–401.

Elkassabany, N.M., D.C. Steinkraus, P. McLeod, J.C. Correll, and T.E. Morelock. 1992. *Pandora neoaphidis* (Entomophthorales: Entomophthoraceae): A potential biological control agent against *Myzus persicae* (Homoptera: Aphididae) on spinach. *Journal of the Kansas Entomological Society* 65:196–199.

Feng, M.G., C. Chen, and B. Chen. 2004. Wide dispersal of aphid-pathogenic Entomophthorales among aphids relies upon migratory alates. *Environmental Microbiology* 6:510–516.

Feng, M.G., R.M. Nowierski, R.E. Klein, A.L. Scharen, and D.C. Sands. 1992. Spherical hyphal bodies of *Pandora neoaphidis* (Remaudiere & Hennebert) Humber (Zygomycetes; Entomophthorales) on *Acyrthosiphon pisum* (Harris) (Homoptera: Aphididae): A potential overwintering form. *Pan-Pacific Entomology* 68:100–104.

Fritz, R. 1976. Action de quelques fongicides sur la croissance mycélienne de trois espèces d'Entomophthorales. *Entomophaga* 21:239–249.

Fritz, R. 1977. Action de quelques fongicides sur des Entomophthorales pathogènes de pucerons. *Phytiatrie-Phytopharmacie* 26:193–200.

Gustafsson, M. 1969. On species of the genus *Entomophthora* Fres. in Sweden III. Possibility of usage in biological control. *Lantbrukshogskolans Annaler* 35:235–274.

Hajek, A.E., and R.J. St. Leger. 1994. Interactions between fungal pathogens and insect hosts. *Annual Review of Entomology* 39:293–322.

Hall, I.M., and P.H. Dunn. 1959. The effect of certain insecticides and fungicides on fungi pathogenic to the spotted alfalfa aphid. *Journal of Economic Entomology* 52:28–29.

Hutchison, W.D., and D.B. Hogg. 1985. Time-specific life tables for the pea aphid, *Acyrthosiphon pisum* (Harris), on alfalfa. *Researches on Population Ecology* 27:231–253.

Lagnaoui, A. 1990. Effects of potato fungicides on entomophthoraceous fungi and the population dynamics of the green peach aphid, *Myzus persicae* (Sulzer). M.S. thesis, University of Minnesota.

Latteur, G. 1973. Étude de la dynamique des populations des pucerons des céréales. Premières données relatives aux organismes aphidiphages en trois localitiés différentes. *Parasitica* 29:134–151.

Latteur, G., and J. Jansen. 2002. Effects of 20 fungicides on the infectivity of conidia of the aphid entomopathogenic fungus *Erynia neoaphidis*. *BioControl* 47:435–444.

Majchrowicz, I., and T.J. Poprawski. 1993. Effects *in vitro* of nine fungicides on growth of entomopathogenic fungi. *Biocontrol Science and Technology* 3:321–336.

Nanne, H.W., and E.B. Radcliffe. 1971. Green peach aphid populations on potatoes enhanced by fungicides. *Journal of Economic Entomology* 64:1569–1570.

Nielsen, C., and A.E. Hajek. 2005. Control of invasive soybean aphid, *Aphis glycines* (Hemiptera: Aphididae), populations by existing natural enemies in New York State, with emphasis on entomopathogenic fungi. *Environmental Entomology* 34:1036–1047.

Nielsen, C., A.E. Hajek, and R.A. Humber. 2003. Soil as an environment for winter survival of aphid-pathogenic Entomophthorales. *Biological Control* 28:92–100.

National Pesticide Information Retrieval System (NPIPRS). 2007. http://ppis.ceris.purdue.edu.

Öncüer, C., and G. Latteur. 1979. The effect of 10 fungicides on the infectivity of conidia of *Entomophthora obscura* Hall & Dunn on the surface of sterile soil. *Parasitica* 35:3–15.

Papierok, B., P. Silvie, J.P. Latgé, C.A. Dedryver, J.M. Rabasse, and G. Remaudière. 1984. Biological control of cereal aphids with Entomophthorales, pp. 339–352. In R. Cavalloro and A. Piavaux (eds.). *C.E.C. Programme on Integrated and Biological Control, Final Report 1979-1983*. EUR 8689, Luxembourg.

Roberts, D.W., and W.G. Yendol. 1971. Use of fungi for microbial control of insects, pp. 125–149. In H. D. Burges and N. W. Hussey (eds.). *Microbial Control of Insects and Mites*. Academic Press, London, UK.

Ruano-Rossil, J.M., E.B. Radcliffe, and D.W. Ragsdale. 2002. Disruption of entomopathogenic fungi of green peach aphid, *Myzus persicae* (Sulzer), by fungicides used to control potato late blight, pp. 365–370. In C.A. Dedryver et al. (eds.). *6th International Symposium: Aphids in a New Millennium. INRA*, Versailles, France.

Smith, M.T., and D.D. Hardee. 1993. Influence of fungicides applied at planting on seasonal development of the entomopathogenic fungus *Neozygites fresenii* (Nowakowski) Batko in the cotton aphid, *Aphis gossypii* Glover, pp. 744–746. In *Proceedings of the Beltwide Cotton Conference*. National Cotton Council of America, Memphis, TN.

Soper, R.S., F.R. Holbrook, and C.C. Gordon. 1974. Comparative pesticide effects on *Entomophthora* and the phytopathogen *Alternaria solani*. *Environmental Entomology* 3:560–562.

Steinhaus, E.A. 1949. *Principles of Insect Pathology*. McGraw-Hill, New York, NY.

Steinhaus, E.A. 1956. Microbial control—The emergence of an idea. *Hilgardia* 27:107–160.

Steinkraus, D.C. 2007. *Cotton Aphid Fungus Sampling Service*. www.uark.edu/misc/aphid.

Steinkraus, D.C., and P.H. Slaymaker. 1994. Effect of temperature and humidity on formation, germination and infectivity of conidia of *Neozygites fresenii* (Zygomycetes: Neozygitaceae) from *Aphis gossypii* (Homoptera: Aphididae). *Journal of Invertebrate Pathology* 64:130–137.

Steinkraus, D.C., G.O. Boys, and J.A. Rosenheim. 2002. Classical biological control of *Aphis gossypii* (Homoptera: Aphididae) with *Neozygites fresenii* (Entomophthorales: Neozygitaceae) in California cotton. *Biological Control* 25:297–304.

Steinkraus, D.C., G.O. Boys, and P.H. Slaymaker. 1993. Culture, storage, and incubation period of *Neozygites fresenii* (Entomophthorales: Neozygitaceae), a pathogen of the cotton aphid. *Southwestern Entomology* 18:197–202.

Steinkraus, D.C., R.C. Hollingsworth, and P.H. Slaymaker. 1995. Prevalence of *Neozygites fresenii* (Entomophthorales: Neozygitaceae) on cotton aphids (Homoptera: Aphididae) in Arkansas cotton. *Environmental Entomology* 24:465–471.

Steinkraus, D.C., M.N. Howard, R.G. Hollingsworth, and G.O. Boys. 1999. Infection of sentinel cotton aphids (Homoptera: Aphididae) by aerial conidia *of Neozygites fresenii* (Entomophthorales: Neozygitaceae). *Biological Control* 14:181–185.

Tanada, Y., and H.K. Kaya. 1993. *Insect Pathology*. Academic Press, San Diego, CA.

U.S. Environmental Protection Agency (US EPA), Office of Pesticide Programs. 2007. *Biopesticide Active Ingredients and Products Containing Them*. www.epa.gov/pesticides/biopesticides/product_lists/bppd-prods-12-16-05.pdf

Vänninen, I., and H. Hokkanen. 1988. Effect of pesticides on four species of entomopathogenic fungi *in vitro*. *Annales Agriculturae Fenniae* 27:345–353.

Wells, L.M., R.M McPherson, J.R. Ruberson, and G.A. Herzog. 2000. Effect of fungicide application on activity of *Neozygites fresenii* (Entomophthorales: Neozygitacaea) and cotton aphid (Homoptera: Aphididae) suppression. *Journal of Economic Entomology* 93:1118–1126.

Wilding, N., and P.J. Brobyn. 1980. Effects of fungicides on development of *Entomophthora aphidis*. *Transactions of the British Mycological Society* 75:297–302.

Wilding, N., and J.N. Perry. 1980. Studies on *Entomophthora* in populations of *Aphis fabae* on field beans. *Annales of Applied Biology* 94:367–378.

Wilding, N., P.J. Brobyn, and S.K. Best. 1978. *Entomophthora* species controlling bean aphids: The effect of fungicides on *Entomophthora*. *Annual Report Rothamstead Experiment Station, 1977 (part 1)*:102–103.

Wilding, N., P.J. Brobyn, and S.K. Best. 1979. *Entomophthora* species controlling bean aphids: The effect of fungicides on *Entomophthora*. *Annual Report Rothamstead Experiment Station, 1978 (part 1)*:97.

Yendol, W.G. 1968. Factors affecting germination of *Entomophthora* conidia. *Journal of Invertebrate Pathology* 10:116–121.

# How to Lose Money Despite High Crop Prices, or Misuses, Misapplications, and Mistakes with Insect Thresholds

*Leon G. Higley*

In the Catskills of New York (Delaware County, to be specific), where my parents grew up on dairy farms, a common perspective was that the only way to make money in farming was to sell the farm. Most of my relatives were eventually forced to follow this advice or take second jobs.

As a kid, I quickly gained the perspective that dairy farming had to be one of the worst ways to try to make a living: There is a constant smell of cow manure; you are tied to the ceaseless milking schedule twice a day; you have to worry about why this or that cow isn't milking; the barn is full of (1) hay (I'm allergic), (2) cows trying to kick or step on you, (3) flies (or fly strips that stick to your hair if you aren't careful), and (4) manure splashing all over; the milk price is never high enough; and did I mention that all the manure has to be shoveled out? Additionally, the alfalfa and silage corn was planted on slopes a Midwesterner would consider a mountainside, and in fields so full of rocks a sane person would be tempted to open a quarry.

Of course, when we visited, I loved getting up early with my Dad to help with milking or to drive the tractor during haying, but even as a child I could see that Dad and Mom's leaving the farm gave us a chance for a much better life.

When I came to Iowa for graduate school and got to plant my soybean plots in some of the flattest, richest soil I'd ever seen, I initially thought that growing field crops was the way to go. The corn yields were like nothing my Dad had ever imagined! In time, however, I learned that it was just as easy to go broke planting corn and beans as it is to go broke milking 40 cows. In fact, one of the most ironic aspects of American agriculture is that what should be good news, such as record yields, often leads to even greater financial problems, because of low prices.

As I've done agricultural research through my career, I've told myself and my students that, because we work on pest management, we are helping protect the environment and helping protect farmers. I guess I still believe that, but I also know that much or most of what we develop isn't used, and problems I saw 30 years ago still exist today. Sometimes research developments aren't practical, broadly applicable, or of much financial impact, so they are never implemented. Sometimes research developments are practical, broadly applicable, and financially beneficial, and they still aren't implemented. This is another irony of agriculture I still don't understand.

All of which finally brings me to the point of this essay. I am supposed to talk about how high crop prices will impact insect thresholds and related pest management decision making. But rather than offer a conventional (read boring) discussion of insect thresholds, I thought I should instead offer a more realistic perspective. As far as I can tell, farming is mostly about losing money, so the real question should be, How can you lose money when crop prices are at record levels? From an insect management perspective, I can show you that losing money isn't hard.

Historically, the most common way to lose money (or your life from starvation) is through acts of God. I think drought stands out among these events, but we shouldn't forget flooding, wind, hail, disease, and (my favorite) insect plagues. The common theme here is that the crop itself is either destroyed or rendered unusable.

To make matters worse, dependence on a single crop presents lots of opportunities for disaster (remember, if you are an American of Irish ancestry, you are almost certainly here because of the Irish potato famine—dependence on a single crop that led to massive death and emigration when

the potatoes rotted from disease). Lack of genetic diversity can also lead to disaster, as evidenced by the loss of all seed corn in 1970 from southern corn leaf blight. (By the way, how much genetic diversity exists in corn and soybean germplasm nowadays?)

More modern approaches to financial ruin in agriculture involve debt. Specifically, debt for equipment (I started to write "extremely expensive equipment" until I realized the "extremely expensive" part is redundant); debt for land (which typically loses value after you buy it); and, if you are really strapped, even debt for pesticides, fertilizer, and seed.

It would be easy to condemn farmers who assume high debt loads were it not for the observation that achieving large economies of scale (becoming more efficient by having larger farms) is essential to having any chance of economic survival (at least in grain crop production). When prices are high, the seeds of future foreclosures often are sown. Why? Because of a mistaken belief that the high yields or high land values or high crop prices will remain at current levels indefinitely. As casino owners know, no matter how good the winning streak, the odds always favor the house. In agriculture, the odds rarely favor farmers for long. So, Leon's first recommendation for how to lose money despite high crop prices: Take out new loans for equipment and land.

As we look at insect pests, there are three basic ways to lose money: fail to act, act too late, or act unnecessarily. Actually, we might include a fourth category, because sometimes, by acting unnecessarily, it is possible to create an insect problem where none would otherwise have existed. Let's look at each of these in more detail, but first let's consider the insects themselves.

Back in the 1930s a guy named Pierce published a paper (Pierce 1934) in which he asked a question I imagine many people had asked before him: How many insects do I need to have in a field before I do something about them? It took about 40 years before anyone came up with a good answer to this question, and, for lots of insects in lots of crops, the jury is still out. Unless you are growing flowers or Christmas trees or other horticultural crops for which people pay based on how the crop looks, the importance of insects is in how they reduce yield.

The simple answer to Pierce's question is that you must prevent more in losses than you spend in managing the insects. Benefits must exceed costs. Entomologists developed guidelines called economic injury levels and economic thresholds to put numbers to this cost–benefit stuff, and, ultimately, scouting and sampling for insects rest on these injury levels and thresholds. Because costs and market values change over time, so should the thresholds.

How do high crop values change the situation? Scientists, like me, live for creating complex models and for requiring years of experiments to answer questions like this. However, it turns out that the crop value question is absurdly easy. The relationship between crop value and damaging insect numbers is a simple inverse. Higher crop value; fewer insects to cause injury.

To offer a specific example, if ten bean leaf beetles per row-foot of soybeans are considered damaging when beans sell for $3 a bushel (ouch), only five beetles are required to cause damage when beans sell for $6 a bushel. [This is just the inverse relationship: Here, crop value doubles ($6/$3 = 2), so the number of insects required is proportionally decreased (10 beetles/2 = 5 beetles)]. Another way to look at this is it to remember that an increase in crop prices essentially changes 98-pound-weakling insects into Charles Atlas–muscled insects: It takes few insects to cause big economic losses. Now, on to losing our shirts ...

Failing to act is a common strategy for incurring economic losses from insects. Don't scout, don't monitor, and, if you do happen to notice any insects or symptoms in the field, don't do anything about it. This is a very common way to lose money with lower-value crops, such as alfalfa, which growers tend not to manage intensely. It is also a common strategy with crops that don't have a history of damaging insect pests.

Soybeans are a good Midwestern example. Most insect pests of soybeans are occasional, but with the introduction of the soybean aphid, potentially damaging insect populations can occur every year. So, maintaining a tradition of not scouting soybeans will almost certainly provide opportunities for large yield losses. With the addition of high soybean prices, low levels of insects that may not have been worth managing in the past may now cause significant economic loss. Leon's second recommendation for how to lose money despite high crop prices: Don't scout your crops and don't adjust your thresholds for new crop prices (= great economic sensitivity to pests).

Acting too late is another great approach for losing money. In the trade, we call this revenge killing. While payback makes a great literary theme (Faulkner's *The Unvanquished* comes to mind) or concept for film (Quentin Tarantino's *Kill Bill* movies), revenge doesn't deter future pest attacks (insects have tiny, little brains and aren't much for memory). Five paragraphs back I said that "you must prevent more in losses than you spend in managing the insects." Regarding acting too late, the key word from this quotation is "prevent." If the insects have already caused a yield reduction, you don't get the yield back by killing them.

All of these calculated insect thresholds are based on the notion that you take action before the insects do their worst. With caterpillars, most of the feeding occurs during the last stage or stages, so taking action before caterpillars are large will prevent most injury. With adults, feeding tends to occur equally over time, so most injury is prevented by acting as soon as adults show up. In contrast, if you wait to take action until most of the insect feeding has already occurred, you not only lose money through yield loss, but you also lose money on unnecessary pesticide use. Leon's third recommendation for how to lose money despite high crop prices: Act too late, after insects have already damaged the crop. Notice that you can actually lose more money with this recommendation than with the second!

Leon's fourth recommendation for how to lose money despite high crop prices has the potential to cost you the most money yet: Take unnecessary action against pests. Ironically, this recommendation has the appearance of saving money, so it is especially well suited to situations with high crop prices. Over the long term, unnecessary use of any management tactic, such as insecticides, increases the likelihood of resistance developing—and resistance can be hugely expensive. But this is a long-term cost, and here I'd like to focus on more immediate ways to lose the farm.

Acting without need is probably the most common of all ways to lose money from insect management. For example, years of research have shown that most corn rootworm insecticides were unnecessary, but when growers couldn't or wouldn't rotate, then the difficulty in predicting potentially damaging field populations required insecticide use as cheap (?) insurance. Treating early-season bean leaf beetles in soybeans (which are almost never damaging) as a mechanism to reduce late-season bean leaf beetles (which are often damaging) is increasingly common, and research shows definitively that this method doesn't work. So, you lose money from the treatment and from later yield loss or from the treatment, the later yield loss, and a revenge killing (the economic losses triple play!).

An important component of the unnecessary actions is the use of seed treatments, systemic insecticides, and tank mixes. In all of these instances, action is being taken in advance of actual knowledge of the pest's existence. Sometimes, the pest is so common that taking early action is a no-brainer (for instance, we know we'll always have weeds), but, in most cases, these early treatments are marketed as less expensive forms of insurance. As far as I can tell, the only real forms of pest insurance are regular scouting or real insurance from an insurance agent (assuming you can find a policy against pests). High crop prices make marketing of "insurance" treatments sound like a prudent course of action, and yet these treatments offer another good opportunity to lose money.

So far, our examination of acting without need has focused on losing money from an unnecessary management action, but the real losses come from creating problems where none would otherwise exist. Now we are entering the major leagues for money loss from poor pest management.

The situation goes like this: First, we take action against a pest when we don't need to, typically before the pest would occur; second, the pest we took action against suddenly appears in high numbers; third, we can chose any of our previous options for losing money by ignoring the pest (big yield loss), treating the pest (losses from an unnecessary and a necessary management action), or acting too late (big yield loss and economic losses from the initial unnecessary action and the revenge killing). Whatever choice we make, we are left with major economic losses that are entirely of our own doing.

The most common current opportunity for this economic train wreck comes with soybean aphid management. Soybean aphid numbers are held in check by natural enemies, and, if we are lucky, these natural enemies can be sufficient to prevent aphids from reaching economic levels. However, many producers have taken to early- or mid-season treatments to kill bean leaf beetles, soybean aphids, and "whatever else" is in the field. The "whatever else" category typically includes natural enemies of soybean aphids; the unnecessary use of insecticide kills the natural enemies, which, in turn, produces an aphid outbreak. The same phenomenon is possible with certain insecticides and spider mites in corn.

Although I've focused on how to lose money, there is always the chance that you'd like to avoid losses. In that case, I also have some advice: Avoid the problems I've outlined here by scouting, using thresholds adjusted for higher crop prices, and taking action against pests only when necessary.

## Reference

Pierce, W.D. 1934. At what point does insect attack become damage? *Entomological News* 45:1–4.

# Tillage and Fertility Placement Aspects of Root Zone Optimization for Corn

*Tony J. Vyn*

Management decisions about root zone optimization should not be limited to corn hybrid selection, because even triple-stacked hybrids with corn rootworm resistance will not produce satisfactory yields if soil structure or chemical properties limit corn growth or nutrient uptake. Growing high-yield corn is possible without intensive tillage systems—numerous studies have shown no-till yielding equal to chisel or moldboard plowing for corn following soybean.

Although maintaining soil-test P and K concentrations well above critical levels is important to achieving optimal corn yields, strip-till corn has not yielded consistently higher when P and K fertilizers were deep banded versus broadcast applied. The relative yield benefits associated with broadcast versus deep-banded application of these nutrients seem to be related to soil moisture availability in the zones of nutrient placement during growing periods, when plants take up the majority of their P and K requirements.

Corn roots and plant populations suffer when corn rows are positioned too close to anhydrous ammonia or urea ammonium nitrate (UAN) N sources incorporated to shallow depths. Precision guidance is very beneficial for optimal corn row positioning at least 5 inches removed from the N fertilizer zone following spring pre-plant N application at high rates.

The primary way to improve stress tolerance (e.g., tolerance to drought, high plant density, or delayed nutrient availability) in corn plants of a given hybrid is to achieve optimal root zones for unimpeded growth in a given soil and climate situation.

## Tillage Aspects

The long-term yield potential of corn with different tillage systems on dark, prairie soils of the Corn Belt has been studied intensively for both the typical corn–soybean rotation as well as for continuous corn. One such study has been ongoing near West Lafayette, Indiana, since 1975 (Table 1). Although equipment, cultivars, and seeding rates were changed periodically, tillage treatments have not been altered during the 32 years of this continuing experiment. The results in Table 1 suggest the following:

- Corn yields are greater in rotation than in continuous cropping for all tillage systems. The positive response to rotation is greatest for no-till corn (18% higher than for the same tillage system when corn follows corn). The positive response to rotation is least with moldboard plowed corn (just 4% higher).
- When corn follows soybeans, yields with plow and chisel are likely to be about the same. Yields from the ridge system may be slightly better (3%) than plow and chisel, but not as good as one would think, given the complete avoidance of traffic on the ridges (rooting zones) over this long-term study. No-till corn yields may be slightly reduced (2%) compared to plow and chisel, but the relative yields of no-till are much lower (14% yield reduction) compared to moldboard plowing when corn is grown continuously. Yield reductions with no-till corn are not due to lower plant populations but to inherently higher plant-to-plant variability (Boomsma and Vyn 2007a). Avoiding soil compaction in no-till corn might be one way for root growth not to be constrained by high soil density.

**TABLE 1 • Corn yield response to tillage and rotation. Long-term tillage study on a dark, prairie silty clay loam soil near West Lafayette, Indiana, 1975–2006.**

| Tillage | Corn/soybean | | Continuous corn | | Yield gain for rotation |
|---|---|---|---|---|---|
| | Bu/A | % of plow yield | Bu/A | % of plow yield | % |
| Plow | 179.7 | — | 172.3 | — | 4 |
| Chisel | 180.0 | 100 | 167.7 | 97 | 7 |
| Ridge* | 184.3 | 103 | 169.1 | 98 | 9 |
| No-till | 175.2 | 97 | 148.3 | 86 | 18 |

*Since 1980.

Root zone optimization is inherently more difficult to achieve in fields where corn follows corn. However, strip tillage systems can result in corn yields equal to those after chisel plowing, even in continuous corn systems (Vyn 2006).

One aspect of the influence of tillage systems on root zones is the changes in organic-matter concentrations at various depths. We recently have observed that, although continuous no-till for 28 years improved soil organic matter near the surface, organic matter in moldboard plowed systems is actually enhanced relative to no-till in the zone from 12 to 20 inches below the soil surface (Gál et al. 2007). We understand from previous research at Purdue University that rooting systems tend to be shallower in no-till than in conventional tillage, but the extent of root proliferation in no-till and strip tillage systems with modern hybrids has not been sufficiently evaluated.

## Fertility Placement Aspects

Continued improvements in fertilizer management practices for corn are warranted because of the linear increase in corn yields since 1950, rapid adoption of less soil-inverting tillage systems since 1990, and a relatively high percentage of low- to medium-testing P or K soils in the eastern Corn Belt states. Broadcast application of non-nitrogen fertilizers remains the most common method throughout the Corn Belt states, but this practice could conceivably increase vertical stratification of less-mobile nutrients such as P and K when used in conjunction with reduced tillage.

Strip tillage represents a promising tillage system aimed at improving the seedbed environment for early corn growth compared to no-till systems. This new management practice, plus the simultaneous deep banding of P and K, could also build soil-test levels in the intended corn row area to potentially improve fertilizer use efficiency by reducing nutrient adsorption and possibly by maximizing plant nutrient uptake. We provided some guidelines for situations where deep banding of P and K might be an advantage in a recent paper (Boomsma et al. 2007).

A 7-year study (2001–2007) was established to address the feasibility of combining strip tillage and deep banding of P and K fertilizers. Five fertility placement alternatives [control, broadcast P+K, banded P+K (6–8 inches), banded K alone (6–8 inches), and banded P alone (6–8 inches)] were spring applied (2001, 2002, and 2003) or fall applied (2004, 2005, and 2006) simultaneously with the strip tillage operation. Two hybrids were evaluated each year from 2001 to 2006, and an application of N-P-K-Zn starter fertilizer (based on 9-18-9) was included at planting, with the exception of 2006–2007, when the starter fertilizer (10-34-0) did not include K. The $P_2O_5$ rate was 88 pounds per acre, and the $K_2O$ rate was 115 pounds per acre; these high amounts were intended to replace the nutrients removed by both corn and soybean in high-yielding situations over the 2-year rotation.

The study was located in two different fields, which were characterized based on their soil-test P concentrations for the standard sampling depth (0–8 inches) in Indiana as very high (>70 ppm) in the site on the even-numbered years but intermediate (10–30 ppm) for the sites in the odd-numbered years. For that reason, we chose to present and analyze the results separately into these two groups.

In most cases, yields for deep-banding and broadcast treatments were not significantly different from each other (Tables 2a and b). Deep-banded P plus K yielded significantly more than broadcast P plus K in only 1 out of 6 years (2004), and these treatments were equally likely to yield significantly more than the check treatment (both yielded more than the check in 3 of 6 years). A significant interaction between hybrids and fertilizer placement was never observed.

The small yield benefit noted from deep banding in 2004 was associated with a year with abundant rain and ample soil moisture availability for root growth and uptake in the zone of nutrient placement during critical growth periods. So, one

**TABLES 2A AND 2B • Effects of deep banding and broadcast fertilizer treatments on strip-till corn yields near West Lafayette, Indiana, 2001–2006.**

| | YEAR | | | | | |
|---|---|---|---|---|---|---|
| | 2001 | 2003 | | | 2005 | |
| Treatment | Yield (bu/ac) | | | | | |
| Broadcast P+K | 220 | 242 | a | | 213 | a |
| Banded P+K | 216 | 236 | a | | 203 | ab |
| Banded K | 210 | 221 | b | | 204 | a |
| Banded P | 224 | 239 | a | | 190 | bc |
| Check | 211 | 221 | b | | 184 | c |
| Hybrid | Yield (bu/ac) | | | | | |
| Pi 34M95 | 220 | Pi 31N28 | 223 | Pi 31N28 | 207 | |
| Pi 34B24 | 212 | Pi 34M95 | 240 | Pi 31G68 | 191 | |

Means with different letters are significantly different (P<0.05)


| | YEAR | | | | | |
|---|---|---|---|---|---|---|
| | 2001 | 2003 | | | 2005 | |
| Treatment | Yield (bu/ac) | | | | | |
| Broadcast P+K | 220 | 242 | a | | 213 | a |
| Banded P+K | 216 | 236 | a | | 203 | ab |
| Banded K | 210 | 221 | b | | 204 | a |
| Banded P | 224 | 239 | a | | 190 | bc |
| Check | 211 | 221 | b | | 184 | c |
| Hybrid | Yield (bu/ac) | | | | | |
| Pi 34M95 | 220 | Pi 31N28 | 223 | Pi 31N28 | 207 | |
| Pi 34B24 | 212 | Pi 34M95 | 240 | Pi 31G68 | 191 | |

Means with different letters are significantly different (P<0.05)


factor in the relative benefit of deep banding may very well be moisture availability for root growth and nutrient uptake in zones of higher nutrient concentrations. Iowa research by Antonio Mallarino has demonstrated fairly conclusively that deep banding of K was most likely to improve corn yields when the month of June was dry. However, if small rainfall events (such as 0.5 inch or less) occur during an otherwise drier than normal month, the broadcast fertilizer may be more available simply because of enhanced moisture availability in the near-surface soil layers.

More recently, we have changed the experiment to test the benefit of deep banding when starter fertilizers are or are not present. The results from 2007 (Figure 1) indicate that corn yields from the broadcast-applied and deep-banded P and K plots were not changed by the presence or absence of starter fertilizer (20 gallons per acre of 10-34-0 in a 2- by 2-inch band). However, starter fertilizer was helpful in improving corn yields in the control plots and those with deep-band K alone.

The most precise, GPS-controlled automatic guidance system currently available for agricultural equipment is the RTK (real time kinematic) system, which allows steering accuracy to within 1 or 2 inches. This tool provides new opportunities for varying crop row position relative to recent (or older) nutrient bands and prior crop rows.

Over the past 2 years, we have evaluated optimal corn row positions following pre-plant UAN application at various N rates. We applied UAN bands with three N rates (50, 100, and 200 pounds per acre) at a depth of 4 inches and seeded no-till corn within 24 hours in rows positioned 0, 5, or 10 inches from these bands. All plots, including a no pre-plant UAN control, received the same total 200 pounds per acre of N by adjustments made in side-dress UAN application after corn emergence.

In 2006, our first year of research at two locations in north central and northwest Indiana, we determined that corn yields were enhanced by on-row or near-row seeding to the pre-plant UAN band at one location when no starter (10-34-0) was applied at planting. However, at another location, corn yields were reduced 22% at the 100 pound pre-plant N rate and 54% at the 200 pound pre-plant N rate with planting directly over the UAN band (Table 3). Lower plant populations (aggravated by limited rainfall) seemed to be the primary cause of the latter yield reductions, though stunted early growth was also evident.

We tentatively conclude that RTK guidance is advantageous when planting corn soon after banded UAN application and that the optimal corn row position for a "safe" response shortly after UAN application at high rates is about 5 inches from, and parallel to, the UAN band. However, continued research in 2007 and 2008 will likely modify our recommendations somewhat.

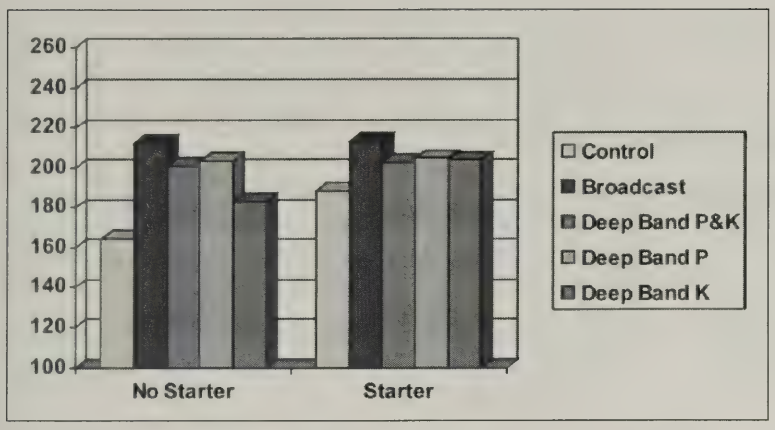


**FIGURE 1 • Effects of deep banding and broadcast fertilizer treatments on strip-till corn yields with and without starter fertilizer application near West Lafayette, Indiana, 2007.**

It is clear that excessive urea or anhydrous ammonia can stunt corn roots and corn shoots when dry soil situations prevail after planting and when N application rates are high. Part of root zone optimization is ensuring that nutrient availability is optimized in the early development of corn plants. Nutrient limitations, as well as nutrient excesses, can limit corn growth and development. Nitrogen placement is a key part of root zone optimization, and this is especially true in no-till and strip-till systems.

## Future Recommendations

Future research in root zone optimization should be much expanded, and it should be done with rootworm-tolerant hybrids as well as for hybrids without insect resistance traits. These studies are inherently labor intensive and costly, but we need to understand corn root responses to management and genotype interactions to provide valid recommendations to crop consultants and growers and to advance our understanding of how to improve corn stress tolerance to drought and other limitations. It is deplorable how little corn root research has been under way in the Corn Belt over the past 2 decades, because so many genetic and management factors have changed.

Perhaps the biggest factor of change in corn root architecture and development rate in a limited soil volume is not the adoption of conservation tillage systems or the rootworm-resistant hybrids but the continued increase in plant density. In the quest for higher yields with modern hybrids, plants, and therefore plant roots, are progressively more crowded. We know that adequate N availability is one means of ensuring that corn plants at progressively higher plant populations are less variable in per-plant grain yield (Boomsma and Vyn 2007b). Maintaining not only optimal overall conditions for root development on a field basis but uniform soil physical and chemical conditions within the corn row area is even more essential at high plant densities.

Automatic guidance systems provide new opportunities for implementing controlled traffic systems within a field during a given year and from year to year. Controlled traffic leads to lower soil compaction, and it is residual soil compaction from random grain buggies, combines, and other field equipment that is perhaps the biggest yield constraint on corn fields that are adequately fertilized and planted to elite hybrids. Avoiding root zone compaction is essential to improve stress tolerance and increase corn yields further. Whether the corn rows should be placed in exactly the same position from one year to the next when corn is grown in the same field (as is possible with RTK guidance) is also

**TABLE 3 • Corn response to pre-plant banded UAN application and RTK-guided corn row placement at Wanatah, Indiana, 2006.**

| Pre-plant N rate and placement | Stand 4 weeks | Plant height V8 | Harvest moisture | Yield at 15.5% |
|---|---|---|---|---|
| | *ppa* | *in.* | *%* | *bu/A* |
| 0 pre-plant UAN | 34306a | 17.3a | 24.9abc | 171.6a |
| 50 lb on-row | 32833a | 16.9a | 24.5bc | 169.2a |
| 50 lb 5 in. | 34417a | 17.8a | 24.6bc | 171.6a |
| 50 lb 10 in. | 34500a | 17.5a | 24.6bc | 168.3a |
| 100 lb on-row | 24417b | 14.0b | 25.5ab | 135.4b |
| 100 lb 5 in. | 33861a | 17.0a | 24.7bc | 174.0a |
| 100 lb 10 in. | 33944a | 17.5a | 23.9c | 173.2a |
| 200 lb on-row | 13306c | 9.9c | 26.3a | 92.6c |
| 200 lb 5 in. | 34556a | 17.1a | 24.8abc | 172.0a |
| 200 lb 10 in. | 34472a | 18.5a | 24.4bc | 170.8a |
| LSD (5%) | 3809 | 2.2 | 1.5 | 17.8 |
| Significance level | 0.01 | 0.01 | NS | 0.01 |

Values followed by different letters are significantly different at P = 0.05.

an important question to investigate in studies that include detailed root investigations of root prolificacy.

## References


Boomsma, C.R., and T.J. Vyn. 2007a. *Plant-to-Plant Uniformity Is Essential for Optimum Yield in No-Till Continuous Corn.* Purdue Extension AY 329-W.

Boomsma, C.R., and T.J. Vyn. 2007b. Plant population influences on maize physiological responses to nitrogen application. *North Central Extension-Industry Soil Fertility Conference Proceedings* 23:136–144.

Boomsma, C.R., M. Cánepa, and T.J. Vyn. 2007. Factors affecting the relative benefit of deep-banding versus broadcast application of phosphorus and potassium for corn and soybean. *North Central Extension-Industry Soil Fertility Conference Proceedings* 23:55–63.

Gál, A., T.J. Vyn, E. Michéli, E.J. Kladivko, and W.W. McFee. 2007. Soil carbon and nitrogen accumulation with long-term no-till versus moldboard plowing overestimated with tilled-zone sampling depths. *Soil Tillage Research* 96:42–51.

Vyn, T.J., 2006. *Meeting the Ethanol Demand: Consequences and Compromises Associated with More Corn on Corn in Indiana.* Purdue Extension ID-336.

# Agronomics for Corn: Have We Exhausted the Easy Options?

*Roger W. Elmore and Lori Abendroth*

Have we picked the "low apples," or, in other words, the easy options, to improve corn yields up to this point? Corn yields across the country continue to increase approximately 1.9 bushels per acre per year. Yet promises of even larger gains abound among seed industry executives. Robb Fraley, Monsanto's chief technology officer, spoke recently of that promise:

> ...conventional plant breeding on average results in 1.5% genetic improvement per year, while molecular breeding—enabled by biotechnology—doubles that rate of improvement. Together, the two approaches promise "to lift the ceiling on yield" (Fitzgerald 2006).

This statement needs clarification. The 1.5% gains cited are not only from genetic improvement. Research identifies that half of observed yield gains are from improved management and half are associated with genetic gains. Therefore, improved national yields from 30 bushels per acre in the early parts of the 20th century to more than 150 bushels per acre today are from improved management *and* genetics.

Realizing that yield improvement has been a combination of these two factors is important to remember as we look to future production and what is possible. Troy Hobbs, Monsanto's corn biofuel strategy leader announced that "... advances in molecular breeding will push [national average yields] to 250 bushels per acre. Additional biotechnology gains will boost the average to 300 bushels per acre by 2030 (Schill 2007).

Promises of increased potential are not only bold but also unrealistic. To achieve 300 bushels per acre national average corn yield by 2030 will require a rate of gain of 6.3 bushels per acre per year. This is more than a threefold increase from the current 1.9 bushels per acre per year.

Projections of this magnitude are made for several reasons, yet we must realistically examine the potential for our future corn acres. Norman Borlaug said at the recent American Society of Agronomy meetings, "You can't eat potential." Stating that a 300 bushels per acre average crop is possible 2 decades from now is only going to cause long-term problems if agribusinesses and political processes ramp up based on this projection.

Projections of this magnitude are made in light of food versus fuel discussions and to alleviate pressure that resources will be limited in the future. Corn grain will be limited in the future if we do not increase the actual yield ceiling of corn. Currently, this is not occurring; average yields are simply getting closer to that ceiling and are expected to plateau somewhere below it. Therefore, to meet the demand for corn in the future will mean that we must continue to increase corn acres or increase corn yields. It is likely that a combination of these approaches will be necessary.

## The "Low Apples"

Unfortunately, we've picked the low apples on the corn yield "tree." We have nearly exhausted many of the management practices that have contributed to the rate of yield gain experienced since the hybrid revolution of the mid-20th century. These "low apples" include the following.

### CROP ROTATION

We understand and, to a large extent, are capitalizing on the yield advantages of rotating corn with other crops, primarily soybeans. Increased acreage allotted to corn following corn is expected to stifle the amount of yield increase observed due to the rotation effect.

## PLANTING DATE

Corn growers across the Corn Belt are planting earlier than ever before. Increased seed quality and seedling cold tolerance contribute to this trend. Seed treatments, seed placement systems on planters, larger planters, high-residue planting systems, and less spring tillage, among other changes, have also contributed to earlier planting dates. Planting earlier than the optimum window has proven fairly stable in terms of yield potential.

Although there is some discussion on the use of seed polymers (which could allow even earlier planting dates by delaying germination until soil temperatures are appropriate), the real question is whether we can plant that much earlier without significantly comprising yield.

## ROW SPACING

Row spacing has varied over the years but has currently stabilized at 30 inches in the central Corn Belt. Further reductions in row width are not expected to increase yields as long as these "wide" rows intercept 95 percent of the available light during pollination and silking. Narrow rows are expected to yield more only if light interception is limited in a particular year. With current planting rates and hybrids, this amount of light interception occurs in an average year.

## SEEDING RATES

Seeding rates continue to increase approximately 400 seeds per acre per year in the central Corn Belt. A final population of 28,000 plants exist on a typical Illinois farm. A significant portion of the yield increases we have experienced in the past 5 decades come from breeders' ability to improve the stress tolerance of plants. Hybrids today are better able to tolerate plant-to-plant competition and produce an ear with less allocated area than ever before.

The question for the future is how much more we can crowd plants together until they will simply not produce a sizeable ear. If a producer is seeding corn at the same rate as 5 years ago, it is still likely that seeding another 2,000 seeds per acre will increase yields.

So, it is possible to continue picking this "low apple" and see increased yields for many producers. But, as seed prices continue to increase, many farmers look at economic returns to seed. Does planting an additional 1,000 seeds cover the cost of the seed? Because most seeding rate curves are relatively flat near the optimum seeding rate, increasing the seeding rate may not increase returns.

## HYBRIDS

At least half of the yield increase experienced in the past 5 decades came from genetic modifications, such as leaf architecture changes and improved stress tolerance. Transgenic hybrids now are a significant portion of new genetics available to the producer. Yet we must remember that transgenics, up to this point, are yield-protection mechanisms and not yield-increasing mechanisms.

Transgenic hybrids have been extremely helpful in protecting the inherent yield potential of a crop in the presence of stress factors (such as herbicides or insects). They have no doubt had some impact on improving average yields, yet they have not improved yield potential (or pushed past the existing yield ceiling) for our very best yielding producers.

## SOIL FERTILITY AND pH

Our understanding of these important variables has increased dramatically in the past 5 decades. The recommendation to use lime is typically based on long-term economics because it improves soil pH over time. Interestingly, recommended nitrogen rates have not increased since the 1980s. Yield gains we have seen since the 1980s have not come from an overall increase in nitrogen applied—although placement and timing have probably been improved—because hybrids today are producing high yields with the same amount of nitrogen as 2 decades ago.

The discussion in progress is whether new hybrids use nitrogen more efficiently. We are currently researching this question along with others. Returns on the use of additional nitrogen (based on the price of corn and the price of the fertilizer) often suggest that current nitrogen application rates are less than those needed to maximize corn yields. Average yields may stagnate or increase less dramatically if producers reduce nitrogen application rates.

## WEED MANAGEMENT

Most producers would agree that weed management is not only easier than ever before, but it is also better than ever before. Although technology is available to allow for excellent weed control, some fields still have weed problems, whether due to improper chemicals used or from spraying too late in relation to crop and weed size. There is clearly room for improvement on the part of some producers, but tools are available to limit yield reductions resulting from weed pressure.

Management steps that are becoming increasingly important are proper stewardship of herbicides and wise resistance management. These actions will help ensure longer use of chemicals and reduce the possibility of weed competition.

### INSECT MANAGEMENT

Producers now manage two key corn insects in the central Corn Belt with transgenic hybrids. Although we will continue to have "escapes" in specific fields and will need to continue to investigate new options and resistance management techniques, we know how to well manage both European corn borer (ECB) and the various strains of the corn rootworm (RW). Other insect pests are present from year to year, but their control in the future is expected to have only a slight impact on yield relative to the impact that controlling ECB and RW has had.

### DISEASE MANAGEMENT

Hybrid improvements in disease tolerance over the decades, coupled with the use of modern fungicides (seed treatments and foliar applied) when pressure exists, have allowed for greater management of diseases better than ever before.

Although many of the yield gains associated with these "low apples" have been realized, it is not possible to start ignoring them. We must continue to work in these areas to continue to manage and maximize their benefits. However, the easy "pickings" from these practices have been realized, and the hardest work lies ahead as we strive to maintain yield improvements with these management techniques.

## The "High Apples"

It is time to get the ladder out! We assert that the secret to improving corn yields lies in the small things that many overlook.

Corn yield contest winners are vigilant about the small and the large issues they can control. Although location plays an important role in yield obtained on small plots, the people involved are in their fields several times a day scouting.

So, what is the difference between average producers and those who produce 300-bushel yields? Location and better management. Producing this amount of grain requires more attention, whether by the producer or a consultant, than what many producers currently give or are willing to give.

Based on the situations we have seen in the past couple of years, here are a few issues that some producers are not paying enough attention to.

### SEEDING DEPTH

Ideal planting depth varies with soil and weather conditions, although a 2-inch depth is ideal for most conditions. Planting depth should never be shallower than 1.5 inches. Some fields have too much variability in depth, which results in variable emergence.

Careful control and attention to planting depth will improve stands and produce more even plant emergence. Uneven emergence will not disappear when the crop gets taller; smaller plants are not able to compete against taller neighbors.

### POOR PLANTING CONDITIONS: SIDEWALL COMPACTION AND OTHERS

Paul Jasa (2007) writes,

> Many factors contribute to sidewall compaction. While wet soil is often given as the main reason, planting too shallow is the primary problem. Most corn planters were designed for a planting depth of 2 to 3 inches, especially those with angled closing wheels. When you properly close the seed-vee, the sidewalls of the furrow should be fractured as the soil closes around the seed, eliminating the sidewalls and providing seed-to-soil contact.
>
> Most sidewall compaction problems on wet soils occur when the press wheels are set with too much downpressure, overpacking the seeds into the soil. When planting shallow, this press wheel compaction is below the seeding depth, making it difficult for the seedling roots to penetrate the soil. ... Make sure that the planter is properly leveled, or even slightly tail down, for the angled closing wheels to have a pinching action to close the seed-vee.
>
> Another contributor to sidewall compaction is the lack of soil structure in many tilled fields. Producers may put extra pressure on the closing devices to close the seed-vee when in wet conditions. Without soil structure, the standard closing wheels "pinch" the sidewalls closed over the seed, particularly in heavier soils. However, as the soil dries, it shrinks and the seed-vee may open back up, exposing the seeds. This often occurs when there is a hot, windy period after planting, drying out the seed zone and reducing the stand. This is less of a problem in higher organic matter soils and in continuous no-till soils with improved soil structure. ... If there is a dry layer on top of the soil at planting time and good soil moisture at planting depth, don't use residue movers or furrow openers to remove the dry soil ... Also, when possible, leave residue over the row to reduce drying of the soil and protect the seed zone from raindrop impact.

Corn that is placed into a wet seed furrow can have restricted root growth, resulting in "rootless" corn (also referred to as rootless corn syndrome), among other problems that will become apparent as the season unfolds. Rootless corn occurs in plants with poorly developed root systems and is usually observed in plants from about the three- to eight-leaf stage of development. During this time, corn exhibiting rootless symptoms have either lodged and are lying on the ground or are about to lodge. Sometimes the corn will be anchored in the soil by only a single nodal root or by seminal roots. Affected plants lack all or most nodal roots. Due to a lack of root mass, the affected plants can wilt, have stunted growth, or die in extreme conditions.

Recovery is severely hampered if conditions are dry. Cultivation to move soil around exposed roots will aid the corn's recovery, yet this is extremely difficult if plants are lying on the ground or in a no-till situation.

The main concern with sidewall compaction and other poor planting conditions is their impact on shoot and root growth of the plants. Stressful early-season environments will reduce yield through several mechanisms: reducing plant populations, increasing plant-to-plant variability, and limiting root growth and/or mass.

### PICKET FENCE SPACING: IMPORTANT OR NOT?

How critical is plant-to-plant spacing for corn? And how does planter speed impact that spacing? Research has shown plant spacing to have variable impact on yield. Some research shows that for every 1 inch in variation from the targeted spacing, yields were reduced 2.5 bushels per acre. Other researchers report even higher losses, while others report significantly less. National yield contest winners often state that slow planter speeds improve plant spacing uniformity and are part of their formula for success.

Fifteen Nebraska producers compared grain yields across different planter speeds in 2001 and 2002. Each location had three to four replications of three planter speeds: 2, 4, and 6 mph. The same study was conducted in 2002 with faster planting speeds: 4, 5.5, and 7 mph. Planter speed did not affect corn grain yield, but it did affect plant spacing accuracy. Grain yields were excellent at all locations, with averages around 200 bushels per acre. Generally, faster speeds resulted in less accuracy than slower speeds; there were more doubles and skips with faster speeds.

We collected spacing variability data from two Iowa farms in 2006 with planter speed trials. Although plant spacing variability was affected by planter speed in the 2006 trials, yields were not consistently affected.

Faster planter speeds affect plant-to-plant spacing. In average (180 bushels per acre) to above-average environments, planter speed does not affect grain yield. But, although not tested, we hypothesize that in very high-yield environments, more-variable spacing will reduce yield potential because of limited space and resources to some plants.

## Summary

We have harvested the low apples on the corn management tree. For yield trends to continue into the next decades, we must pick the high apples, which are harder to get. To maximize grain yield in high-yielding environments, each plant must look like every other plant. Producers should target factors that decrease plant-to-plant variability.

We are convinced that corn management must focus on the small things in order to reach the next phase of corn yields. Management techniques, coupled with genetic improvements that push strongly against or beyond the current yield ceiling, will, we hope, continue corn yields across the Corn Belt. This will, however, require greater effort on the part of producers, agronomists, consultants, and researchers. It time to stretch the ladder out!

## References


Fitzgerald, A. 2006. 300 bushels per acre corn yield no longer a pie-in-sky goal. *Des Moines Register*, December 10.

Jasa, P. 2007. *Crop Watch* No. 07-8 (April 20). University of Nebraska Institute of Agriculture and Natural Resources Cooperative Extension, Lincoln, NE.

Schill, S.R. 2007. 300-bushel corn is coming. *Ethanol Producer Magazine*, October.


## For More Information

**Seeding depth**
www.extension.iastate.edu/Publications/PM1885.pdf

**Side wall compaction**
http://cropwatch.unl.edu/archives/2007/crop8/sidewall_compaction.htm

**Planter speed**
www.agronext.iastate.edu/corn/production/management/planting/planter.html

**Uneven heights and yield impacts**
www.agronext.iastate.edu/corn/production/management/early/heights.html
www.agronext.iastate.edu/corn/production/management/early/height.html

# Corn Nematode Management

*Terry L. Niblack*

Every corn plant in every field is host to an array of plant-parasitic nematodes. Some of the very common species we see in Illinois are capable of causing significant corn yield loss under certain conditions. Yet we don't often hear about nematode injury to corn, and nematodes are usually the last item on the list when corn growers or consultants are searching for the cause of poor corn yields. This is partly because it is difficult to diagnose corn nematode injury and partly because there are few options for managing nematode problems once they are diagnosed.

## Why Corn Nematode Problems Are Becoming an Issue Now

Changes in corn production practices in the recent past have increased the risk for yield loss due to nematodes. As most growers have probably heard by now, these risk factors include no-till, continuous corn, and the use of GMOs for corn insect management.

- No-till, while an excellent choice for a number of reasons, increases the risk for injury by certain types of plant-parasitic nematodes, including those commonly known as dagger, stubby root, and the very damaging needle nematodes. Research on nematode communities in a number of ecosystems has shown us that nematodes in this group are very sensitive to soil disturbance. Remove the disturbance, and populations of these nematodes are able to increase.
- Continuous corn encourages the increase of corn parasites of all kinds, of course. But it is most encouraging for corn-parasitic nematodes for two interconnected reasons. First, many of the corn parasites have long life cycles or produce few offspring (in comparison with soybean cyst nematode), and they take a long time to build up to damaging levels. Second, many of the corn parasites are not well adapted to soybeans (although they may be able to survive well enough), so when the fields are rotated, these nematodes have less opportunity to increase.
- Genetic modifications effective for management of corn root insects are not effective for root-feeding nematodes. Some of the carbamates and organophosphates that were used formerly in insect pest management programs had the added side benefit of suppressing nematode infection.

## Symptoms of Corn Nematode Damage: The "Hidden Enemy"

Nematode damage is usually suspected when stunted, yellow plants are seen in irregularly shaped areas varying in diameter from a few square yards to several acres. However, typical symptoms may be much more subtle. Plants may exhibit uneven growth; nutrient deficiencies; wilting during bright, hot days, followed by recovery at night; small ears with poor grain fill; poor yields not associated with other problems such as insect damage, fertility, or other agronomic factors; and areas of excessive root or stalk rots.

Root injury symptoms vary with the nematode species, population density, soil conditions, and plant age. Symptoms of nematode root damage include the following:

- Short and thick ("stubby") roots, often arranged in clusters. The injury may resemble damage from dinitroanaline herbicides. This damage is associated with needle, stubby root, and sting nematodes.
- Shallow root systems with few fine feeder roots. This damage may be observed on old and young plants. Damage

by grape colaspis larvae may resemble this type of nematode damage on young seedlings. This damage may be associated with dagger, stunt, and sting nematodes.

- Root systems with few fine roots, with root lesions, and root rot. This type of injury is often associated with invasion by other microorganisms. Damage by lesion, dagger, lance, and spiral nematodes may be of this type.

## Diagnosis

Because corn nematode damage resembles so many other problems, the only way to get a positive diagnosis is to take a soil sample and submit it to a qualified lab for analysis. For general information on soil sampling for nematodes, see http://web.aces.uiuc.edu/vista/pdf_pubs/1100.PDF. In addition, consider the following points:

- Sample as deeply as possible, when the soil is moist but not wet. A good time to sample is early in the season (say, a month to 6 weeks after emergence), but samples can be collected at any time. Although it's usually recommended to sample somewhere between 6 and 12 inches deep, it may be necessary to take deeper samples if the plants are large or the soil is dry.
- Treat the samples *gently* while they're being taken and afterward, because some corn nematodes are very sensitive to manipulation and can be killed before they reach the lab. Dead nematodes are often very difficult to identify and are often ignored during analysis.
- Sample around the edges (not in the centers) of "hot spots" in the field.
- Place the sample in a plastic bag—not a paper bag—to help keep it moist during transport, and store the sample in a cooler to keep the nematodes from being cooked!

In addition to the sample itself, include information on previous field history, soil fertility, soil condition, herbicide use during the current and preceding year, distribution of the problem, and appearance of above- and below-ground parts of the plant. Corn nematode management depends on the nematode species involved and how high their numbers are, so it's very important to get a good sample as the basis for a reliable diagnosis.

## Management of Corn Nematode Problems

This point cannot be emphasized strongly enough: *specific recommendations depend absolutely on getting a good diagnosis.* Each of the following general recommendations must be tailored to the diagnosis.

- Avoid stress. Water infected plants, if irrigation is available. Fertilize according to soil tests. Stress makes plants more susceptible to injury from nematode feeding.
- Control weeds, especially grasses. Weeds are hosts for many nematodes and may serve as "reservoirs" for damaging nematodes.
- Rotate "hot spots" to a crop other than corn, but be aware that many nematodes that attack corn also attack soybeans, wheat, or other crops.
- Use chemical control if possible. Registered chemicals for nematodes may be found by searching for "nematode" on the Illinois Department of Agriculture Web site at www.kellysolutions.com/IL/searchbypest.asp.

Many companies have become aware that corn nematode problems are increasing in high-yield production areas. Several are currently evaluating new products, or re-evaluating old ones, for nematode control on corn. At this writing, the results from the 2007 field evaluation season have not yet been analyzed, but several products look at least promising. New information and recommendations should be forthcoming in the near future.

# Foliar Fungicides in Corn Production: A Look at Local and Regional Data

*Carl A. Bradley and Keith A. Ames*

In 2007, a record number of corn acres were sprayed with a foliar fungicide in Illinois and other midwestern states. High market prices and an increasing demand for ethanol made from corn, along with more corn-on-corn production, were factors that influenced this sharp increase in foliar fungicide use. Despite dry conditions and low levels of disease in much of Illinois in 2007, many fields received a foliar fungicide application.

No "hard and fast" IPM-based fungicide guidelines or disease thresholds have been developed for commercial hybrid corn production in the Midwest. This is due, in part, to the historical lack of foliar fungicides used in corn and the lack of foliar fungicides registered for use in corn until recently.

Tilt (propiconazole; Syngenta Crop Protection) was the first systemic fungicide registered for use on corn in the United States. More recently, fungicides in the "strobilurin" chemistry class such as azoxystrobin, pyraclostrobin, and trifloxystrobin have become registered on corn. These strobilurin fungicides are either marketed alone [e.g., Quadris (azoxystrobin; Syngenta Crop Protection) and Headline (pyraclostrobin; BASF Corp.)] or are in a pre-mix combination with the "triazole" fungicide propiconazole [e.g., Quilt (azoxystrobin + propiconazole; Syngenta Crop Protection) and Stratego (trifloxystrobin + propiconazole; Bayer CropScience).

Munkvold et al. (2001) reported that a foliar application of propiconazole to control gray leaf spot (caused by *Cercospora zeae-maydis*) could be profitable in Iowa, but the profitability of a propiconazole application was strongly influenced by the susceptibility of the corn hybrid to gray leaf spot. In other words, it was more likely to receive a positive return on the fungicide investment if it was applied to a susceptible hybrid. Similarly, Ward et al. (1997) reported that gray leaf spot severity and yield loss could be reduced with a propiconazole application to a susceptible hybrid in South Africa.

Although "hard and fast" fungicide guidelines do not exist for corn, fungicide application decisions can be made, in part, based on risk factors. A gray leaf spot risk-assessment model developed by Paul and Munkvold (2004) indicated that corn residue on the soil surface, planting date, and hybrid resistance to gray leaf spot were among the best predictors for gray leaf spot. Risk of gray leaf spot increases with increasing corn residue on the soil (de Nazareno et al. 1993), later planting date (Rupe et al. 1982), and greater hybrid susceptibility. These three risk factors can be determined prior to planting. A "post-planting" risk factor is weather, where rainfall and relative humidity play a role in providing an environment favorable for disease (Rupe et al. 1982).

Along with these risk factors, it is still important to scout the crop and collect disease observations. If low levels of disease are present, it is unlikely that a fungicide will provide an economic benefit despite the presence of pre-plant risk factors.

## A Look at 2007 Corn Foliar Fungicide Data from Illinois

Several foliar fungicide trials were conducted on corn across several locations in Illinois in 2007. Some of these trials were basic fungicide trials that examined the effect of different fungicides on disease control and yield of one corn hybrid. Other trials were more complicated and evaluated multiple factors such as previous crop, different corn hybrids, simulated hail damage, and fungicides.

### "BASIC" FUNGICIDE TRIALS

Trials located near Urbana (Champaign County), Ridgway (Gallatin County), and Dixon Springs (Pope County) were conducted to test different foliar fungicides on a corn hybrid

moderately susceptible to gray leaf spot. In the Urbana trial (Table 1), all of the foliar fungicides significantly reduced gray leaf spot severity compared to the untreated control; however, none of the fungicides provided a significant increase in yield over the untreated control. In the Ridgway trial (Table 2), no significant differences occurred among the different treatments for gray leaf spot severity or yield. In the Dixon Springs trial (Table 3), foliar fungicides significantly reduced gray leaf spot severity compared to the untreated control; however, no significant differences were observed for yield. In all three of these trials, foliar disease pressure was low, with the highest observed severity rating being only 20%.

**TABLE 1 • Effect of foliar fungicides applied at tassel emergence on gray leaf spot severity and yield of a moderately-susceptible corn hybrid near Urbana, Illinois, in 2007.**

| Fungicide | Rate/A | GLS severity[1] | Yield (bu/A) |
|---|---|---|---|
| Untreated | | 20 | 214 |
| Quilt | 14 fl oz | 10 | 191 |
| Headline | 6 fl oz | 6 | 208 |
| Stratego | 10 fl oz | 10 | 217 |
| Stratego | 12 fl oz | 9 | 215 |
| | LSD[2] | 4 | 19 |

[1] Gray leaf spot severity (0-100% scale).

[2] Fisher's protected least significant difference ($\alpha = 0.05$).

**TABLE 2 • Effect of foliar fungicides applied at tassel emergence on gray leaf spot severity and yield of a moderately susceptible corn hybrid near Ridgway, Illinois, in 2007.**

| Fungicide | Rate/A | GLS severity[1] | Yield (bu/A) |
|---|---|---|---|
| Untreated | | 15 | 153 |
| Quadris | 6 fl oz | 15 | 158 |
| Quadris | 9 fl oz | 11 | 164 |
| Headline | 6 fl oz | 10 | 155 |
| Headline | 9 fl oz | 13 | 160 |
| Stratego | 10 fl oz | 9 | 162 |
| Stratego | 12 fl oz | 9 | 159 |
| Quilt | 14 fl oz | 10 | 164 |
| | LSD[2] | NS[3] | NS |

[1] Gray leaf spot severity (0-100% scale).

[2] Fisher's protected least significant difference ($\alpha = 0.05$).

[3] Not significantly different ($P \leq 0.05$) according to *F*-test.

**TABLE 3 • Effect of fungicides applied at tassel emergence on gray leaf spot severity and yield of a moderately-susceptible corn hybrid near Dixon Springs, Illinois, in 2007.**

| Fungicide | Rate/A | GLS severity[1] | Yield (bu/A) |
|---|---|---|---|
| Untreated | | 15 | 183 |
| Quadris | 6 fl oz | 7 | 167 |
| Quadris | 9 fl oz | 5 | 179 |
| Headline | 6 fl oz | 7 | 192 |
| Headline | 9 fl oz | 7 | 171 |
| Stratego | 10 fl oz | 7 | 169 |
| Stratego | 12 fl oz | 8 | 159 |
| Quilt | 14 fl oz | 5 | 171 |
| | LSD[2] | 2 | NS[3] |

[1] Gray leaf spot severity (0-100% scale).

[2] Fisher's protected least significant difference ($\alpha = 0.05$).

[3] Not significantly different ($P \leq 0.05$) according to *F*-test.

## SIMULATED HAIL × FUNGICIDE TRIAL

From the authors' perspectives, recommendations to apply a foliar fungicide to a corn field after a hail storm have not been based on data from replicated research trials. A trial was conducted near Champaign to evaluate the effects of foliar fungicides on gray leaf spot and yield under simulated hail damage and no hail damage conditions.

Hail damage was simulated by damaging corn plants with a weed-eater type gasoline string mower at tassel emergence, and foliar fungicides were applied the following day. In this trial (Table 4), foliar fungicides significantly reduced gray leaf spot severity compared to the untreated control in both the simulated hail damage and no hail damage plots. Within simulated hail damage and no hail damage plots, foliar fungicides did not significantly affect yield compared to the untreated controls. Overall, yields from the simulated hail damage plots were significantly lower than yields from the no hail damage plots.

## PREVIOUS CROP × HYBRID × FUNGICIDE TIMING TRIAL

A trial was conducted near Urbana to evaluate the effect of previous crop (soybeans or corn), corn hybrid, and fungicide timing on gray leaf spot severity and yield. To establish this trial, corn was planted no-till into either corn or soybean

stubble. A hybrid moderately resistant to gray leaf spot and a hybrid moderately susceptible to gray leaf spot were used in this trial. Stratego fungicide was applied at either VT or R1. An untreated control was also included. In this trial (Table 5), significant differences in gray leaf spot severity were observed between the two hybrids; however, Stratego did not significantly reduce gray leaf spot severity compared to the untreated control within each previous crop–hybrid combination. No significant differences in yield were observed.

**TABLE 4 • Effect of simulated hail damage and foliar fungicides applied at tassel emergence on gray leaf spot severity and yield of a susceptible corn hybrid near Champaign, Illinois, in 2007.**

| Simulated hail[1] | Fungicide | Rate/A | GLS severity[2] | Yield (bu/A) |
|---|---|---|---|---|
| No | Untreated | | 57 | 174 |
| | Headline | 6 fl oz | 33 | 179 |
| | Quadris | 6 fl oz | 42 | 170 |
| | Quilt | 14 fl oz | 40 | 155 |
| Yes | Untreated | | 62 | 141 |
| | Headline | 6 fl oz | 48 | 144 |
| | Quadris | 6 fl oz | 47 | 142 |
| | Quilt | 14 fl oz | 35 | 140 |
| | | LSD[3] | 12 | 11 |

[1] Hail was simulated by damaging corn plants with a weed-eater type string mower.

[2] Gray leaf spot severity (0-100% scale).

[3] Fisher's protected least significant difference ($\alpha = 0.05$).

### FUNGICIDE × CORN HYBRID TRIALS

Munkvold et al. (2001) reported that hybrid susceptibility to gray leaf spot influenced the probability of a profitable fungicide application. To evaluate the effect of foliar fungicides on different corn hybrids, two trials were conducted. One trial, conducted at both Monmouth (Warren County) and Champaign, investigated the effects of eight fungicide treatments (including an untreated control) on five different corn hybrids. At the Monmouth location (Table 6), some of the foliar fungicides significantly reduced gray leaf spot severity compared to the untreated control for hybrid 3; however, fungicides did not affect gray leaf spot severity within any of the other hybrids. Within hybrids at Monmouth, the only fungicide that provided a significant yield increase over the untreated control was Stratego applied at 10 fl oz/A for hybrid 2.

At the Champaign location (Table 6), foliar fungicides generally provided a significant reduction in gray leaf spot severity; however, severity was very low across all hybrids. Some foliar fungicides provided a significant yield increase over the untreated control for hybrid 1 and hybrid 4, but fungicides did not affect yield compared to the untreated control in any of the other hybrids.

## Conclusions

Based on University of Illinois corn fungicide trials conducted in 2007, "automatic" significant yield increases with the use of foliar fungicides did not occur. Even though the fungicides tested had good efficacy against gray leaf spot, a reduction in disease severity did not always translate into a yield benefit. This could have been due, in part, to the fact that almost every trial conducted in 2007 had low disease pressure and never reached disease levels that could cause economic yield losses. Using the pre-planting risk factors (i.e., amount of corn residue, hybrid susceptibility, and planting date) along with the post-planting risk factors (i.e., weather conditions, scouting observations) to make fungicide application decisions will increase profitability and reduce unwarranted fungicide applications.

## Acknowledgments

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## References

de Nazareno, N.R.X., P.E. Lipps, and L.V. Madden. 1993. Effect of levels of corn residue on the epidemiology of gray leaf spot of corn in Ohio. *Plant Disease* 77:67–70.

Munkvold, G.P., C.A. Martinson, J.M. Shriver, and P.M. Dixon. 2001. Probabilities for profitable fungicide use against gray leaf spot in hybrid maize. *Phytopathology* 91:477–484.

Paul, P.A., and G.P. Munkvold. 2004. A model-based approach to preplanting risk assessment for gray leaf spot of maize. *Phytopathology* 94:1350–1357.

Rupe, J.C., M.R. Siegel, and J.R. Hartman. 1982. Influence of environment and plant maturity on gray leaf spot of corn caused by *Cercospora zeae-maydis*. *Phytopathology* 72:1587–1591.

Ward, J.M.J., M.D. Laing, and D.C. Nowell. 1997. Chemical control of maize grey leaf spot. *Crop Protection* 16:265–271.

**TABLE 5 • Effect of previous crop, corn hybrid, and Stratego fungicide on gray leaf spot severity and yield near Urbana, Illinois, in 2007.**

| Previous crop | Hybrid[1] | Fungicide, rate/A | Timing | GLS severity[2] | Yield (bu/A) |
|---|---|---|---|---|---|
| Corn | Mod Res | Untreated | | 7 | 200 |
| | | Stratego, 10 fl oz | VT | 5 | 198 |
| | | | R1 | 5 | 205 |
| | Mod Susc | Untreated | | 13 | 208 |
| | | Stratego, 10 fl oz | VT | 10 | 213 |
| | | | R1 | 13 | 208 |
| Soybean | Mod Res | Untreated | | 5 | 205 |
| | | Stratego, 10 fl oz | VT | 4 | 211 |
| | | | R1 | 4 | 213 |
| | Mod Susc | Untreated | | 10 | 219 |
| | | Stratego, 10 fl oz | VT | 8 | 222 |
| | | | R1 | 10 | 225 |
| | | | LSD[3] | 4 | NS[4] |

[1] One hybrid was moderately resistant to gray leaf spot, and the other hybrid was moderately susceptible to gray leaf spot.

[2] Gray leaf spot severity (0-100% scale).

[3] Fisher's protected least significant difference (alpha = 0.05).

[4] Not significantly different ($P \leq 0.05$) according to *F*-test.

**TABLE 6 • Effect of corn hybrid and foliar fungicides applied at tassel emergence on gray leaf spot severity and yield near Monmouth and Champaign, Illinois, in 2007.**

| | | | Monmouth | | Champaign | |
|---|---|---|---|---|---|---|
| Hybrid | Fungicide | Rate/A | GLS severity[1] | Yield (bu/A) | GLS severity[1] | Yield (bu/A) |
| 1 | Untreated | | 19 | 231 | 4 | 163 |
| | Quadris | 6 fl oz | 13 | 236 | 3 | 173 |
| | Quadris | 9 fl oz | 13 | 234 | 2 | 181 |
| | Headline | 6 fl oz | 14 | 236 | 2 | 176 |
| | Headline | 9 fl oz | 14 | 239 | 2 | 182 |
| | Stratego | 10 fl oz | 14 | 233 | 2 | 181 |
| | Stratego | 12 fl oz | 15 | 230 | 3 | 174 |
| | Quilt | 14 fl oz | 14 | 233 | 2 | 185 |
| 2 | Untreated | | 22 | 252 | 6 | 178 |
| | Quadris | 6 fl oz | 18 | 249 | 2 | 178 |
| | Quadris | 9 fl oz | 15 | 244 | 2 | 183 |
| | Headline | 6 fl oz | 17 | 263 | 2 | 182 |
| | Headline | 9 fl oz | 16 | 268 | 2 | 183 |
| | Stratego | 10 fl oz | 15 | 270 | 2 | 178 |
| | Stratego | 12 fl oz | 17 | 246 | 3 | 189 |
| | Quilt | 14 fl oz | 17 | 252 | 3 | 177 |
| 3 | Untreated | | 43 | 239 | 6 | 181 |
| | Quadris | 6 fl oz | 28 | 240 | 3 | 175 |
| | Quadris | 9 fl oz | 37 | 237 | 3 | 194 |
| | Headline | 6 fl oz | 29 | 240 | 4 | 187 |
| | Headline | 9 fl oz | 33 | 243 | 3 | 187 |
| | Stratego | 10 fl oz | 43 | 237 | 4 | 186 |
| | Stratego | 12 fl oz | 36 | 239 | 4 | 184 |
| | Quilt | 14 fl oz | 25 | 245 | 4 | 186 |
| 4 | Untreated | | 21 | 237 | 6 | 150 |
| | Quadris | 6 fl oz | 22 | 240 | 3 | 163 |
| | Quadris | 9 fl oz | 21 | 234 | 3 | 162 |
| | Headline | 6 fl oz | 21 | 242 | 4 | 158 |
| | Headline | 9 fl oz | 19 | 239 | 3 | 165 |
| | Stratego | 10 fl oz | 21 | 242 | 4 | 160 |
| | Stratego | 12 fl oz | 18 | 240 | 3 | 157 |
| | Quilt | 14 fl oz | 23 | 236 | 3 | 155 |
| 5 | Untreated | | 25 | 255 | 5 | 188 |
| | Quadris | 6 fl oz | 18 | 263 | 3 | 182 |
| | Quadris | 9 fl oz | 22 | 254 | 4 | 185 |
| | Headline | 6 fl oz | 18 | 262 | 5 | 174 |
| | Headline | 9 fl oz | 18 | 263 | 4 | 195 |
| | Stratego | 10 fl oz | 22 | 257 | 3 | 192 |
| | Stratego | 12 fl oz | 24 | 256 | 3 | 184 |
| | Quilt | 14 fl oz | 24 | 269 | 4 | 175 |
| | | LSD[2] | 9 | 18 | 2 | 15 |

[1] Gray leaf spot severity (0-100% scale).

[2] Fisher's protected least significant difference ($\alpha = 0.05$).

# The Seven Wonders of the Corn Yield World

*Fred E. Below*

## An Introduction to the Seven Wonders

I developed the "Seven Wonders of the Corn Yield World" as a tool to teach farmers and crop consultants the relative importance of management factors that can impact corn productivity. The seven wonders ranks the top seven factors that can positively impact corn yields and assigns an average bushel per acre value to each wonder. It is based on a compilation of research conducted by the Crop Physiology Laboratory at the University of Illinois over the past 10 years. Because the bushel values are averages of ranges, farmers of course could experience different values, and, because the research for this ranking was conducted mostly in Illinois, the relative ranking or value of a particular wonder could change slightly with geography.

There are some practices that are clearly important, but I don't consider them yield wonders because they are one-time improvements (e.g., tile drainage or waterways), they protect rather than increase yield (e.g., weed or pest control), or they involve decisions that do not need to be made every year (e.g., soil pH and nutrient levels). In my view, good weed control, along with proper soil pH and adequate levels of P and K, are prerequisites for crop production and are necessary to allow the seven wonders to express their positive impact on grain yield.

One nuance of the seven wonders is that they can interact with each other to either magnify or lessen a single wonder's impact on yield. Also, as a rough rule, the higher the ranking of a particular wonder, the more control it can exert over the wonders below it. Understanding a wonder's ranking, and its interaction with other wonders, gives farmers an opportunity to further increase grain yields through crop management.

## Least Control on Wonders One and Two

Unfortunately, the first wonder of the corn yield world is the one that farmers have the least control over, the **weather**. Weather, largely in the form of rainfall and temperature, is a major determinant of when the crop can be planted, and it has a huge impact on plant growth and yield potential (Thompson 1986; Anderson et al. 2001). Even with the other yield wonders optimized and constant, our research shows a 70+ bushel variation in grain yield due to the weather. All farmers know that weather can circumvent their best management plans, because it so strongly interacts with each of the other yield wonders.

Especially affected by weather is **nitrogen** fertilization (N), the number two wonder of the corn yield world. The ability to apply fertilizer N, its availability or susceptibility to loss, and its impact on grain yield are all heavily impacted by weather. As a result, weather and the availability of N are usually the two factors exerting the greatest impact on corn yields. They can act independently, or be closely linked, and their effects can be to either increase or decrease crop growth and yields. A lot of research has been conducted to try to understand and manage the interaction between weather and N (IPNI 2007).

One example of the many possible interactions between weather and N is shown in Figure 1. There is a considerable impact of year (weather) on the maximum yield, and on the response to N, for corn grown at the same location. In this case, low July rainfall limited yield in 2005 and lowered the need for and the response to fertilizer N. Other examples could just as easily show increases in the magnitude of response to N due excess rainfall causing N losses. Because N fertilizer increases grain yield by an average of 70 bushels, and because most of

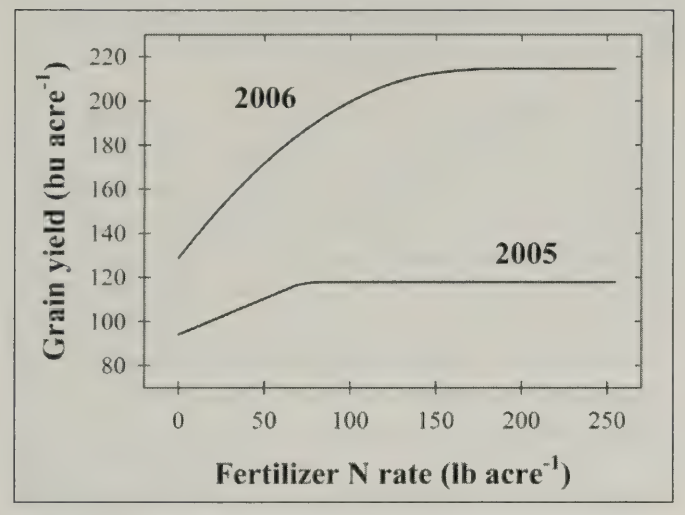


**FIGURE 1 • The interaction between weather and N on the grain yield of corn.** Data are the average of multiple hybrids grown at the same site in Champaign, Illinois, in 2005 and 2006.

the other yield wonders can also impact the availability or the use of N, N fertilizer management continues to receive considerable attention in the research world.

## Wonders Three and Four Gaining in Importance

Nitrogen use also interacts strongly with the third wonder of the corn yield world, **hybrid** selection, and there is considerable interest in improving the efficiency of N use with genetics or biotechnology (Hirel et al. 2007). Hybrid selection is probably the most important decision made by farmers, and most do not realize the large difference in yield potential among elite commercial hybrids. Arrays of commercial hybrids, grown under conditions where the other wonders are presumed to be optimized, typically exhibit a 50-bushel range in grain yield. An example of this difference is shown in Table 1. The weather effect on average yield is clear, but in each year the hybrids still exhibit close to a 50-bushel range in yield. Clearly, hybrids respond differently to growing conditions, and hybrid selection will become even more important in the future, when biotechnology adds stress and input traits such as drought tolerance and improved N use.

There is a hint that biotechnology may have already altered hybrid N use via Bt rootworm resistance. I have seen big yield advantages conferred by the rootworm trait that are hard to attribute entirely to rootworm control. One of these studies is shown in Figure 2, which illustrates the results of our comparison of N response for the same hybrid with varying biotech trait combinations. Plots had fairly low rootworm pressure and were treated with soil insecticide at planting, so it is hard to believe that the 50+ yield advantage of the triple-stack version was solely attributable to rootworm control. The triple-stack hybrid performed better at low N and had an even higher maximal yield at high N, but it required more total N to achieve its maximum yield (Figure 2). Additionally, we have seen cases where inclusion of the

**TABLE 1 • Variation in grain yield of commercial hybrids over a 4-year period at Champaign, Illinois. Values for each hybrid are at the N rate that optimized yield.**

| Year* | Average | Range bu/A | Delta |
|---|---|---|---|
| 2004 | 200 | 178–229 | 51 |
| 2005 | 119 | 94–136 | 42 |
| 2006 | 188 | 152-215 | 63 |
| 2007 | 196 | 173-221 | 48 |

*24, 22, 17, and 15 hybrids in each respective year.

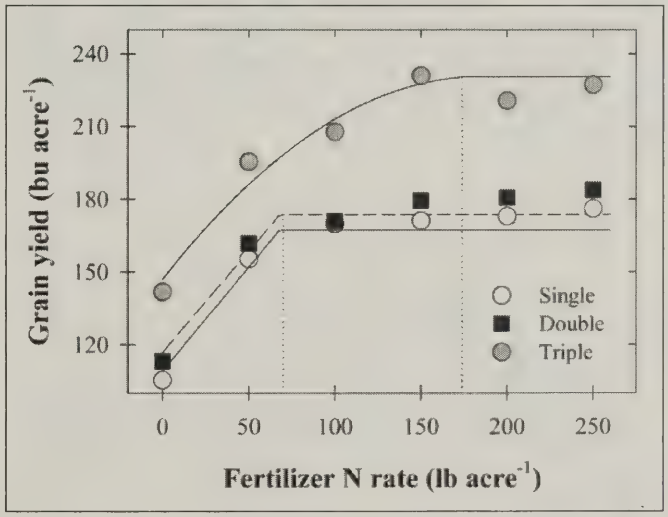


**FIGURE 2 • Influence of combinations of biotech traits on the response of corn grain yield to fertilizer N.** The same hybrid genetics were used for the single (herbicide resistance only), the double (herbicide resistance and corn borer Bt), and the triple (herbicide resistance, corn borer Bt, and rootworm Bt) stack versions. All plots also received soil insecticide at planting. The dashed lines at the inflection points indicate the N rate associated with maximum yield. Data are from a 2006 experiment conducted at Champaign, Illinois.

rootworm trait increased yield without altering the N level needed for maximum yield, and where yield increases along with a decrease in the N level needed for maximal yield (data not shown). Although more work needs to be done to ascertain the full impact of the rootworm Bt trait on N use, these examples bode well for future improvements with biotechnology.

The fourth wonder of the corn yield world, **previous crop**, is gaining in importance as the acreage of continuous corn has steadily increased. This is despite the 25-bushel per acre yield penalty associated with continuous corn, and the higher input cost, especially fertilizer N. Previous crop clearly interacts with the first and second wonders, and, if sufficient N is available in a good growing year, we have found that the continuous corn yield penalty can be reduced or eliminated (Becker et al. 2007) (Figure 3). Conversely, in the poorer growing year (2005), the yield penalty from continuous corn could not be overcome with additional N.

Although it makes sense that some hybrids might perform better than others under continuous corn, our research has not shown this (Becker et al. 2007). When each hybrid's average yield in continuous corn is plotted against its yield in rotation, none performs better under continuous corn in either year—all are above the 1:1 line (Figure 4). For both years, there is a highly significant linear association between a hybrid's yield in rotated and continuous corn ($r$ = 0.92 and 0.99 for 2005 and 2006, respectively), which means that the best hybrid for rotated corn is also the best one for continuous corn.

## Are Interactions the Key to Wonders Five, Six, and Seven?

Wonders five, six, and seven have a smaller individual impact on yield, but a larger possibility for interactions with wonders one through four (weather, N, hybrid, and previous crop). It is well known that the fifth wonder of the corn yield world, **plant population**, has increased steadily over the past 20 years (Duvick 2005). But what probably is not known is how well modern hybrids are at flexing their ear components (i.e., kernel number and weight) to account for differences in plant stand. Because of this, we find similar yields between 28,000 and 40,000 plants per acre, although there is a big difference in the size of individual kernels. An example of this is shown in Figure 5 for a series of on-farm variable rate population studies. Thus, most of the 20-bushel yield benefit that we see from plant population comes from correcting stands that are too low.

Plant population, however, interacts heavily with most of the other yield wonders, with high plant populations being particularly susceptible to unfavorable weather conditions. Similarly, some hybrids are clearly more tolerant to high populations than others, and previous crop and tillage can impact plant population by altering seed germination and seedling emergence. One interaction we do not observe, however, is between plant population and N rate (Figure 6). Contrary to what many farmers and crop consultants think, we do not see a requirement for higher N rates as plant populations increase.

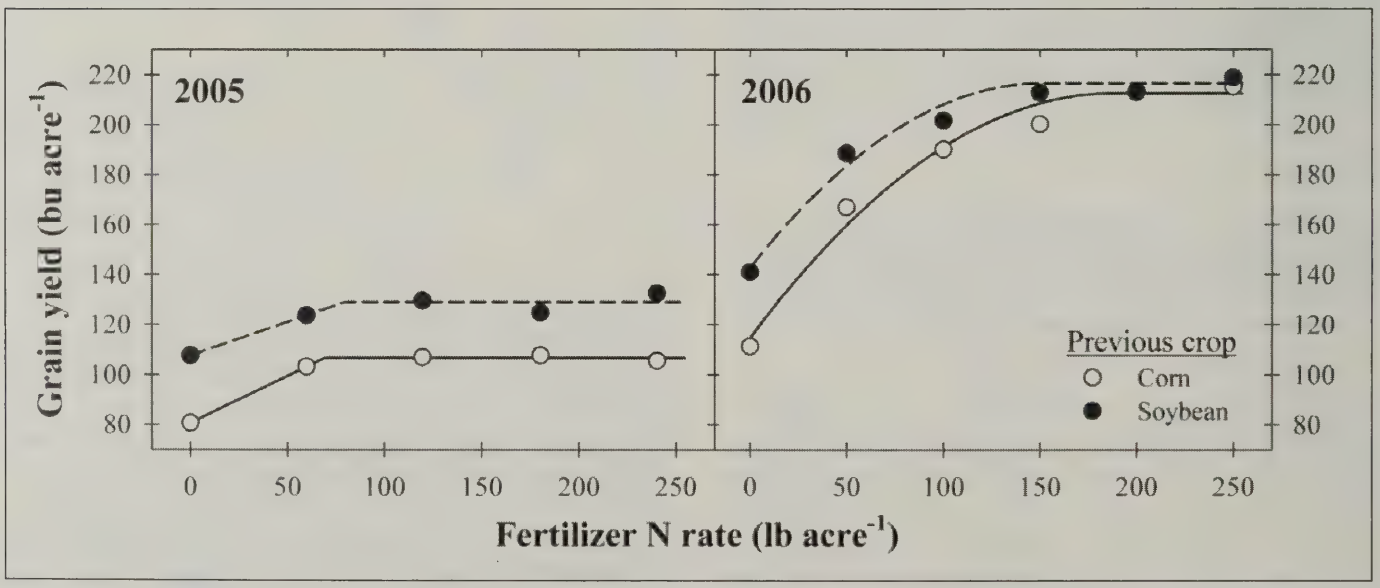


**FIGURE 3 • Effect of previous crop and fertilizer N rate on grain yield for two contrasting years at Champaign, Illinois.** Yields are averaged over 22 hybrids in 2005 and 12 in 2006.

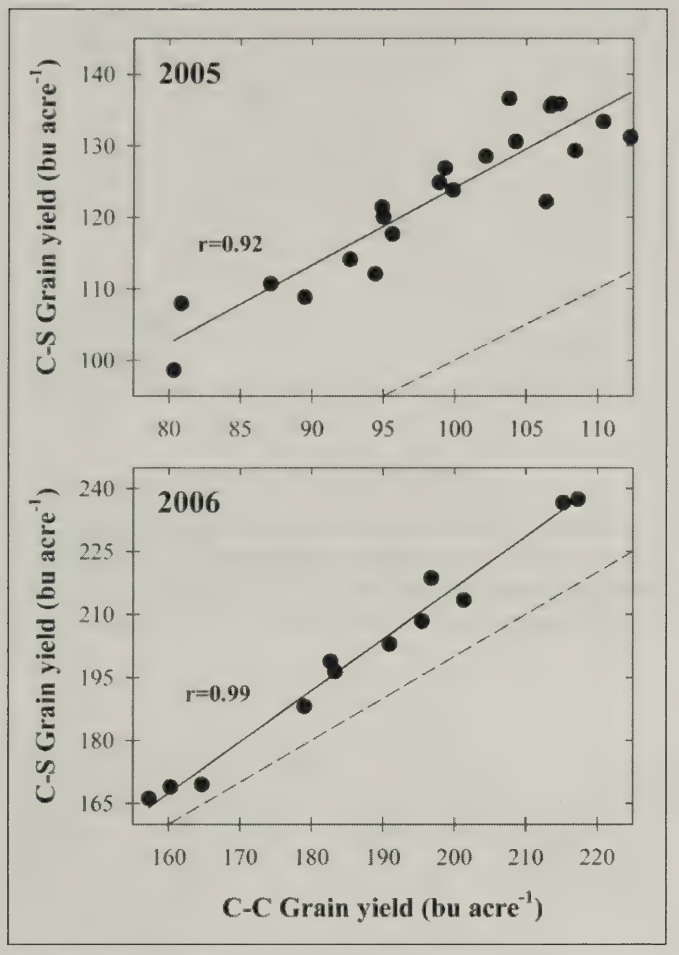


**FIGURE 4 • The relationship between a hybrid's yield in continuous corn (C-C) and its yield when rotated with soybean (C-S) for the 22 and 12 hybrids evaluated in 2005 and 2006, respectively.** Hybrid values are averaged over N rates. The dashed line depicts the one-to-one relationship, and the solid line the linear regression among hybrids for 2005 ($y = 1.085x + 15.58$) and for 2006 ($y = 1.2227x - 28.24$).

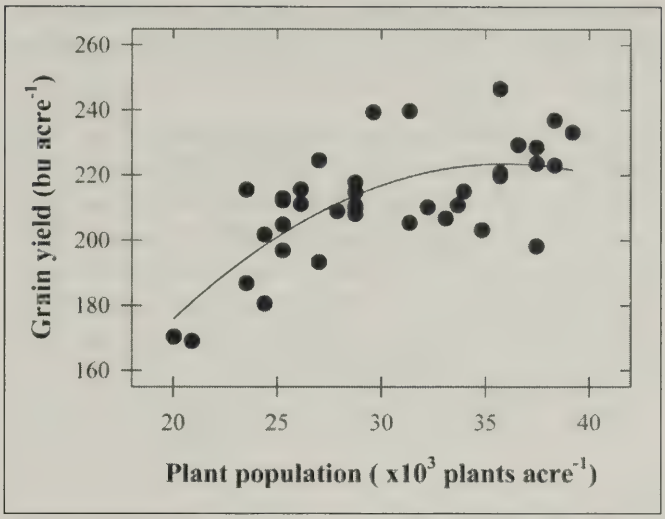


**FIGURE 5 • The effect of varying plant populations on grain yield of corn.** Data were collected on-farm from a large-scale variable rate seeding study conducted near Beardstown, Illinois, in 2005.

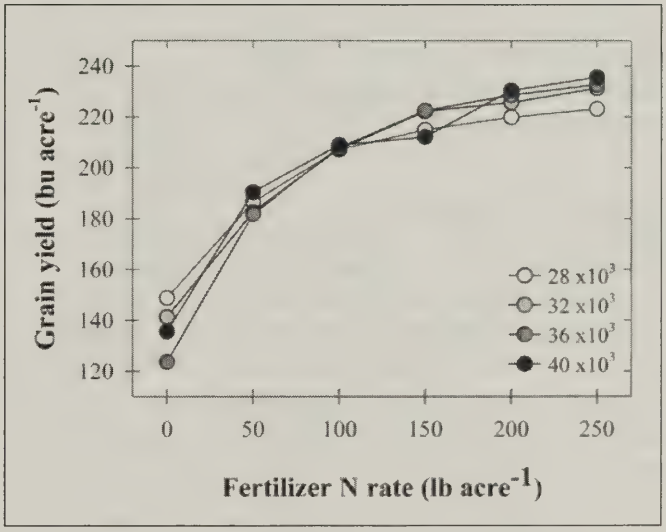


**FIGURE 6 • The interactive effect of plant population and N rate on grain yield of corn.** Yields are averaged over 12 hybrids grown at Champaign, Illinois, in 2006.

The sixth wonder of the corn yield world, **tillage**, comes in varying degrees, or at differing times. Both aspects interact heavily with the other yield wonders, with the relative advantages or disadvantages of a particular tillage system or time depending largely on the weather, and often interacting with N availability and hybrid. An example of the interaction between tillage and N rate is shown in Figure 7. At low N rates, tillage systems have an advantage over no-till, while the opposite is true at high N rates. This interaction is likely due to the impact of tillage on N availability and the water-holding capacity of the soil. The degree of tillage and the time of tillage can also make a big difference with previous crop because most of the yield penalty associated with continuous corn is due to the residue (Gentry et al. 2001). Similarly, the tillage system can have a big impact on plant population. Overall, our research shows a 15-bushel yield range from the various tillage systems.

The seventh wonder of the corn yield world is a catch-all that I call **chemicals**. This includes plant growth regulators and compounds that exert growth regulator-like effects that, as a result, lead to a positive change in growth or yield determina-

tion. Late-season leaf-greening from certain foliar fungicides and ethylene-sensing technologies that make the plant less sensitive to environmental stresses fit into this category.

An example of the late-season greening effect induced by Headline fungicide is shown in Figure 8. Leaves below the ear of Headline-treated plants exhibited a slower rate of decline during the later stages of grain fill, while the leaves above the ear were much less affected. Translation of leaf greening into higher grain yield, however, was highly dependent on the weather, particularly July rainfall (Figure 9). The likelihood of a Headline effect on grain yield was closely related to the site's total rainfall in July, which explained 82% of the variability in the magnitude of yield change. Leaf-greening, however, was only beneficial to yield when July rainfall was greater than normal, and it did not overcome the yield limitation imposed by low July rain. Thus, like all plant growth-regulating compounds, there is also the possibility for detrimental effects depending on how the other wonders are altering plant growth at the time of application. Although the overall average is a positive 10 bushels, the success of these compounds is highly dependent on the other yield wonders, especially weather and hybrid, and this category has the widest range.

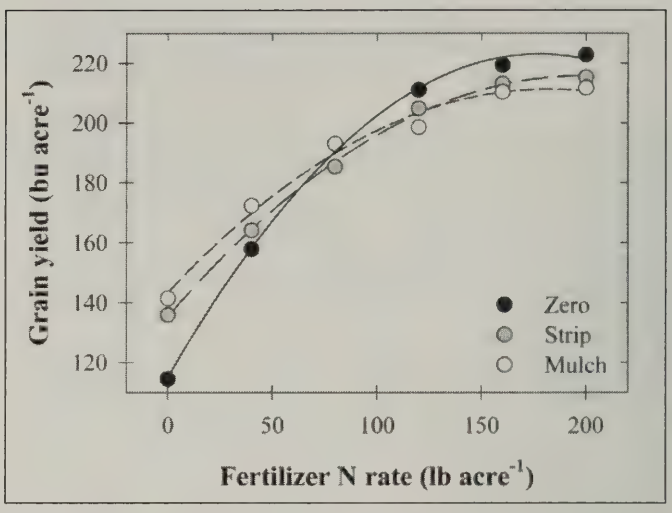


**FIGURE 7 • The interactive effect of tillage type and N rate on grain yield of corn.** Yields are averaged over 6 site-years in northern and central Illinois between 1999 and 2000.

## They All Add Up

Each of the seven wonders and its average impact on yield is shown in Table 2. By optimizing all of the seven wonders and using my average number for each wonder's value, grain yields of 260 bushels should be the result. This does not take interactions among the wonders into account, which in some cases could drive yields even higher. By the same token, a nonoptimized yield wonder lowers yield. Although I realize that my seven wonders concept is a vast oversimplification of all the complicated factors that make a high-yielding corn crop, I still hope that it gives you a better perspective on how your management decisions can impact grain yield.

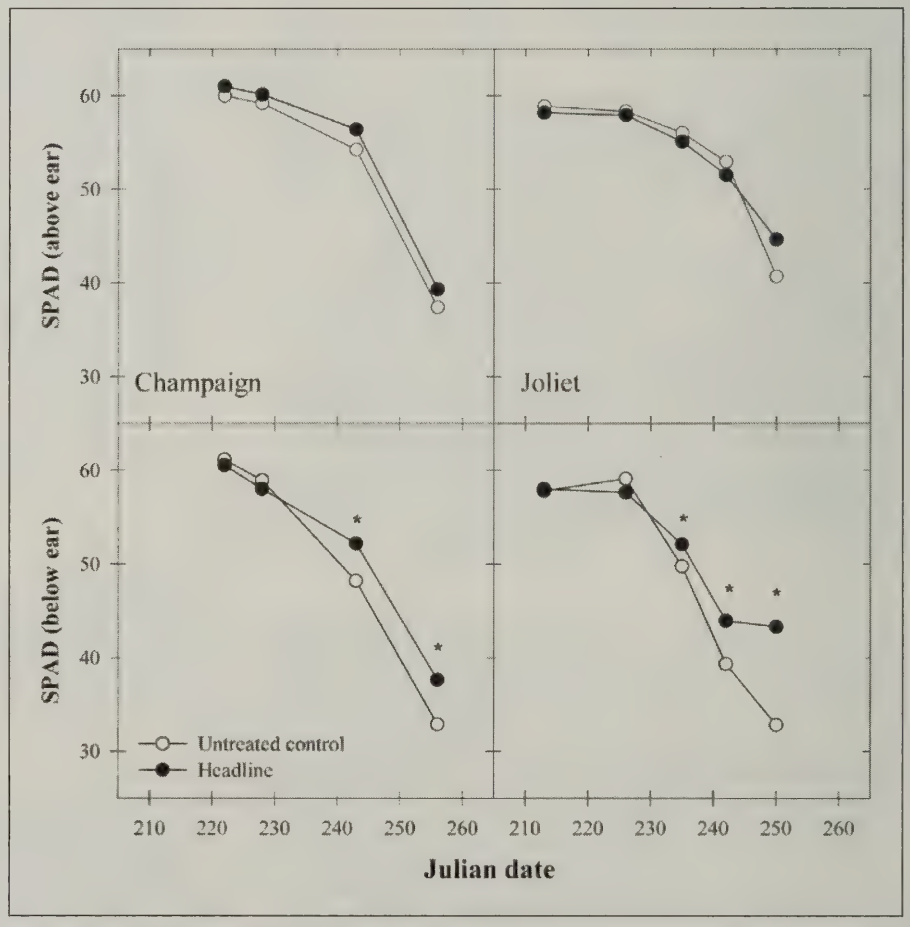


**FIGURE 8 • The effect of Headline application (near stage VT) on leaf relative greenness (SPAD) during grain fill (measured above and below the ear) for corn grown at Champaign and Joliet, Illinois, in 2006.** (*) Indicates significant differences between control and Headline-treated plants for any given sampling day.

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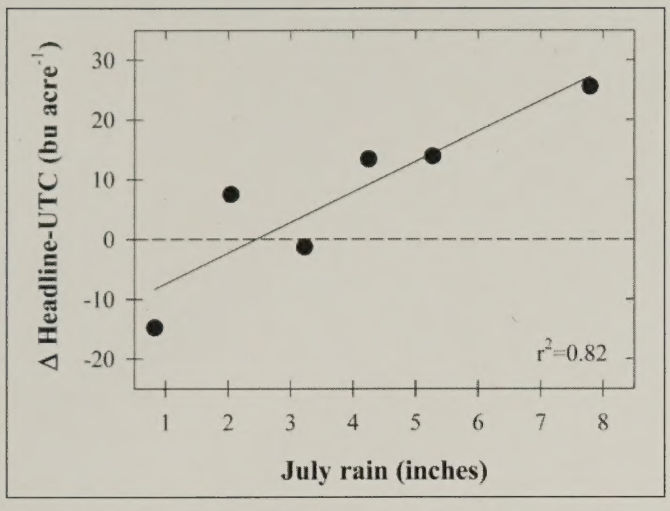


**FIGURE 9 • The relationship between total rainfall in July and the magnitude of yield response to a Headline application (near stage VT) for corn grown at six sites in Illinois in 2006.**

**TABLE 2 • The seven wonders of the corn yield world.**

| Rank | Factor | Value bu/A |
|---|---|---|
| 1 | Weather | 70+ |
| 2 | Nitrogen | 70 |
| 3 | Hybrid | 50 |
| 4 | Previous crop | 25 |
| 5 | Plant population | 20 |
| 6 | Tillage | 15 |
| 7 | Chemicals | 10 |

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## References

Anderson, J.A., G. Alagarswamy, C.A. Rotz, J.T. Ritchie, and A.W. LeBaron. 2001. Weather impacts on maize, soybean, and alfalfa production in the great lakes region, 1898–1996. *Agronomy Journal* 93:1059–1070.

Becker, A.W., M.L. Ruffo, and F.E. Below. 2007. Hybrid selection and fertilizer nitrogen on the yield penalty of continuous corn. *Field Crops Research* (submitted).

Duvick, D.N., 2005. The contribution of breeding to yield advances in maize (*Zea mays* L.). *Advances in Agronomy* 86:83–145.

Gentry, L.E., F.E. Below, M.B. David, and J.A. Bergerou. 2001. Source of the soybean N credit in maize production. *Plant Soil* 236:175–184.

Hirel, B., J. Le Gouis, B. Ney, and A. Gallais. 2007. The challenge of improving nitrogen use efficiency in crop plants: Towards a more central role for genetic variability and quantitative genetics within integrated approaches. *Journal of Experimental Botany* 58:2369–2387.

International Plant Nutrition Institute (IPNI). 2007. *Managing Crop Nitrogen for Weather. Proceedings of the Soil Science Society of America Symposium on Integrating Weather into Nitrogen Recommendations.* 15 November 2006, Indianapolis, IN. International Plant Nutrition Institute, Norcross, GA.

Thompson, L.M. 1986. Climate change, weather variability, and corn production. *Agronomy Journal* 78:649–653.